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Registered Office : 406, Taj Apt., Ring Road, Near Safdarjung Hospital, New Delhi-110029
Web: mtg.in Email: info@mtg.in

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Physical World and Measurement

Scope and Excitement of Physics

Scope of physics lies in its various sub-disciplines. Basically there are two domains of interest, macrosopic and microscopic. The microscopic domain includes phenomena at the laboratory terrestrial and astronomical scales. The microscopic domain of physics deals with the constituent and structure of matter at the minute scales of atoms and nuclei and their interaction with other elementary particles like electrons, photons etc.

Physics is exciting in many ways. To some people the excitement comes from the elegance and universality of its basic theories, from the fact that a few basic concepts and laws can explain about physical quantities. To some others, the challenge is carrying out imaginative new experiments to unlock the secrets of nature is thrilling.

Nature of Physical Laws

Physicists explore the nature and abural phenomenon. They investigate on the bases of scientific processes. In addition to finding the facts, by observation and experimentation, physicists try to discover the laws that summarize there facts. Physicists have found several conservation laws which include conservation of momentum, energy, angular momentum, charge and mass. Conservation laws are different in character from Newton's law of motion and gravity, but they are just as fundamental, useful and important. Conservation laws can provide useful information about a system.

Not all quantities in physics are conserved. For instance, there is no conservation of force or conservation of velocity. But the quantities that are conserved, such as momentum, energy etc. are important properties to know about an object. Current research in physics aims at determining these properties for everything ranging from subatomic particles to astronomical objects.

Physics, Technology and Society

Physics and society are connected with each other, as most of the inventions in physics have a direct impact on society. When the principles of physics are applied for practical purposes, it is known as technology. Physics try to discover the rules or principles that govern natural processes or phenomena and then technologists apply them for betterment of everyday life.

Units of Measurement

Measurement is basically a process of comparison. A quantity that can be measured and by which various physical happenings can be explained and expressed in the form of laws is called a physical quantity. Measurement of any physical quantity involves comparison with a certain basic, arbitrarily chosen, internationally occupied reference standard called unit.

Physical quantity is represented completely by its magnitude and unit.

Physical quantity = Magnitude × unit

Fundamental and Derived units

Any unit which cannot be expressed in terms of other units is called a fundamental unit. For example, unit of mass, length and time are fundamental units. Other units which can be expressed in terms of fundamental units are called derived units. For example, unit of velocity, energy etc. are derived units.

System of Units

- A complete set of both fundamental and derived units for all kind of physical quantities is called a system of units. Such system of units include, CGS System, MKS System, FPS System and SI System.
- The base units for length, mass and time in their systems are as follows :
- In CGS system, they are centimeter, gram and second respectively.
- In FPS System, they are foot, pound and second respectively.
- In MKS System, they are meter, kilogram and second respectively.
- SI system is also known as international system of units and it is an extended MKS system of units. The given table shows the units for all the base quantities in SI system.

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Physical quantity	Units (SI)	Notations
Mass	kg(kilogram)	M
Length	m(metre)	L
Time	s(second)	T
Temperature	K(kelvin)	θ
Electric current	A(ampere)	I or A
Luminous intensity	cd (candela)	cd
Amount of substance	moles	mol

There are also two supplementary quantities in addition to the seven fundamental quantities. They are

- **Plane angle :** Unit of plane angle is radian and its symbol is rad.
- **Solid angle :** Unit of solid angle is steradian and its symbol is sr.

Measurement of Length

- Length of an object is the distance of separation between any two points at the extreme ends of it. Most common unit of length is metre.
- One metre is the length of the path travelled by light in vacuum is 1/299, 792, 458 of a second.

Range of Length

- 1 fermi = 10^{-15} m
- 1 angstrom = 10^{-10} m
- 1 astronomical unit = 1.496×10^{11} m
- 1 light year = 9.46×10^{15} m
- 1 parsec = 3.2 light year = 3.08×10^{16} m

Measurement of Mass

- Mass is the basic property of matter and is equal to the quantity of matter contained in the body. The SI Unit of mass is kilogram, while dealing with atoms and molecules, the standard unit of mass is unified atomic mass unit (amu).
- One kilogram is defined as the mass of international prototype standard block of platinum, iridium alloy preserved in the international Bureau of weights and measures.
- One amu is $(1/12)^{th}$ of the mass of an atom of carbon 12 isotope.

Measurement of Time

- The most common unit of time is second. One second is the duration of 9, 192, 631, 770. Periods of radiation corresponding to unperturbed transition between the two hyperfine levels of the ground state of Cs - 133 atom.
- **Range of Time :** Time interval of an event varies over wide range from 10^{-24} s which is the life span of most unstable particle to 10^{17} s which is the approximate age of the universe.

Accuracy and precision of measuring instrument

Measurement is a part of doing experiments in science. The result of every measurement by any measuring instruments contains some uncertainty. This uncertainty in measurement is known as error. Accuracy of a measurement means how close the measured value is to the true value of a physical quantity. The limit of resolution to which a physical quantity is measured by a measuring instrument is known as its precision.

Types of Error

- **Systematic error :** It is the error due to known causes. The measurement errors that are unidirectional in nature, which means they are either positive or negative.
- **Personal errors :** These measurement errors occur due to the improper setting of the apparatus or an individual's carelessness in taking observations without following the required precautionary measures.
- **Instrumental errors :** These errors occur due to faulty or wrongly calibrated measuring instruments. For example if the zero of the vernier scale and main scale do not coincide, it may cause error in measurement and such type of error is called zero error.
- **Imperfection in experimental technique or procedure :** An error occurring in the measurement of a physical quantity due to wrong experimental technique or procedure gives rise to systematic errors.
- **Random errors :** It is the error due to unknown causes.
  These errors occur due to unpredictable variations in experimental conditions, such as fluctuations in temperature, voltage supply, and mechanical vibrations of experimental setups are known as random errors. These errors occur irregularly and vary in size and sign (positive or negative).
- **Least count error :** It is the error associated with the resolution of the measuring instruments.

Absolute Error, Relative Error and Percentage Error

Absolute Error

- The difference between the measured value and the true value gives the error in measurement.
- Let a physical quantity be measured n times. Let the measured values be $a_1, a_2, a_3, ..., a_n$, The arithmetic mean of these values is

$$a_m = \frac{a_1 + a_2 + ... + a_n}{n}.$$

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- The error in the measured values of the physical quantity are

$$\Delta a_1 = a_m = a_1,$$
$$\Delta a_2 = a_m = a_2,$$
$$\vdots$$
$$\Delta a_n = a_m - a_n.$$

- Absolute error Δa is always positive and is denoted by $|\Delta a|$.
- Hence the final result of measurement after including the absolute error may be written as $a = a_m \pm \overline{\Delta a}$, where $\overline{\Delta a}$ is the mean absolute error.
- Mean absolute error is the arithmetic mean of the absolute errors in all the measurements of a physical quantity.

$$\overline{\Delta a} = \frac{|\Delta a_1| + |\Delta a_2| + \ldots + |\Delta a_n|}{n}$$
$$= \sum_{i=1}^{n} \frac{|\Delta a_i|}{n}$$

Relative Error

Relative error of a measurement is defined as the ratio of the mean absolute error to the mean value of the physical quantity measured.

$$\text{Relative error} = \frac{\text{Mean absolute error}}{\text{Mean value}}$$
$$= \frac{\Delta a}{a_m}$$

Percentage Error

When the relative error is expressed in percentage it is known as percentage error.

$$\delta a = \frac{\Delta a}{a_m} \times 100\%$$

Combination of Error

- **In sum** : If $Z = A + B$, then the maximum absolute error in Z is

$$\Delta Z = \Delta A + \Delta B$$

- **In difference** : If $Z = A - B$, then the maximum absolute error in Z is

$$\Delta Z = \Delta A + \Delta B$$

- **In product** : If $Z = AB$, then the maximum relative error in Z is given by

$$\frac{\Delta Z}{Z} = \frac{\Delta A}{A} + \frac{\Delta B}{B}$$

Maximum percentage error in Z is

$$\frac{\Delta Z}{Z} \times 100 = \frac{\Delta A}{A} \times 100 + \frac{\Delta B}{B} \times 100$$

- **In division** : If $Z = A/B$, then the maximum relative error in Z is

$$\frac{\Delta Z}{Z} = \frac{\Delta A}{A} + \frac{\Delta B}{B}$$

Maximum percentage error in Z is

$$\frac{\Delta Z}{Z} \times 100 = \frac{\Delta A}{A} \times 100 + \frac{\Delta B}{B} \times 100$$

- **In power** : If $Z = A^m$, then the maximum relative error in Z is given by

$$\frac{\Delta Z}{Z} = m\frac{\Delta A}{A}$$

Maximum percentage error in Z is

$$\frac{\Delta Z}{Z} \times 100 = m\frac{\Delta A}{A} \times 100$$

In more general form if $Z = \frac{A^p B^q}{C^r D^s}$

Maximum relative error in Z is given by

$$\frac{\Delta Z}{Z} = p\frac{\Delta A}{A} + q\frac{\Delta B}{B} + r\frac{\Delta C}{C} + s\frac{\Delta D}{D}$$

Maximum percentage error in Z is

$$\frac{\Delta Z}{Z} \times 100 = p\frac{\Delta A}{A} \times 100 + q\frac{\Delta B}{B} \times 100 + r\frac{\Delta C}{C} \times 100 + s\frac{\Delta D}{D} \times 100$$

Significant Figures

The result of a measurement of a physical quantity is a number which includes reliable digits plus the first uncertain digits, which is known as significant figures.

Rules to find Significant Figures

- **Rule-1:**
  All non-zero digits are significant. *e.g.* 1324 has four significant figures.
- **Rule-2 :**
  All zeros occuring between two non-zero digits are significant. *e.g.* 120024 has 6 significant digits.
- **Rule-3 :**
  If the number is less than 1, the zero(s) on the right of decimal point, but to the left of the first non-zero digit are not significant. *e.g.* 0.00064 has two significant digits.
- **Rule-4 :**
  In a number without a decimal point the terminal or trailing zero(s) are not significant. *e.g.* 227800 have four significant digits.
- **Rule-5 :**
  In a number with a decimal point the trailing zero(s) are significant. *e.g.* 3.200 or 0.05400 have four significant digits each.

  Note : The power (or exponent) of 10 is irrelevant to the determination of significant figures. For example, 3.100×10^2 has 4 significant figures.

  The change of units only changes the order of exponent but not the number of significant figures. *e.g.* 1.40 m = 1.40×10^2 cm both have three significant figures.

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Dimensions of physical quantities

Physical quantities can be expressed in terms of seven fundamental units. These seven fundamental quantities are called as the seven dimensions of physical world denoted by mass [M], length [L], time [T], current [A], temperature [K], luminous intensity [cd] and amount of substance [mol].

Dimensional analysis

Dimensions : The dimensions of a physical quantity are the powers (or exponents) to which the base quantities are raised to represent that quantity.

Dimensional formula : The expression which represents the dimensions of a physical quantity.

Dimensional equation : An equation obtained by equating a physical quantity with its dimensional formula is known as the dimensional equation of the physical quantity.

- The dimensional formula for frequency, angular frequency, angular velocity, and velocity gradient are same. *i.e.* $[M^0L^0T^{-1}]$.
- Strain, Poisson's ratio, refractive index, relative permittivity, relative permeability, relative density, angle, solid angle and trigonometric ratios have no dimensions *i.e.* $[M^0L^0T^0]$.
- Relative velocity has the dimensions of velocity. *i.e.* $[M^0LT^{-1}]$.
- Work, kinetic energy, potential energy, internal energy, heat, torque, couple and moment of force have the same dimensional formula $[ML^2T^{-2}]$.
- Surface tension and spring constant have the same dimensional formula $[ML^0T^{-2}]$.
- Momentum and impulse have the same dimensional formula, $[MLT^{-1}]$.
- Acceleration due to gravity has the same dimensional formula as gravitational intensity $[M^0LT^{-2}]$.
- Force, thrust and weight have the same dimensional formula $[MLT^{-2}]$ as the energy gradient.
- Angular momentum and Planck's constant have the same dimensional formula $[ML^2T^{-1}]$.
- Electric field strength and potential gradient have the same dimensional formula $[MLT^{-3}A^{-1}]$.
- **Homogeneity principle :** If the dimensions of left hand side of an equation are equal to the dimensions of right hand side of the equation, then the equation is dimensionally correct. This is known as homogeneity principle.
- **Dimensional variables :** These are the quantities whose values are variable, and they possess dimensions. *e.g.* area, volume, density, velocity, acceleration, force etc.
- **Dimensional constants:** These are the quantities whose values are constant and they possess dimensions. *e.g.* universal gravitational constant, universal gas constant, Boltzmann constant, Planck's constant etc.
- **Dimensionless variables :** These are the quantities, whose values are variables, and they do not have dimensions. *e.g.* angle, strain, specific gravity etc.
- **Dimensionless constants :** These are the quantities, whose values are constant, but they do not possess dimensions. *e.g.* pure numbers 1, 2, 3, 4, ..., mathematical constants π and '*e*' etc.

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EXAM DRILL

1. If the energy, $E = G^p h^q c^r$, where G is the universal gravitational constant, h is the Planck's constant and c is the speed of light, then the values of p, q and r are, respectively

(a) $\frac{-1}{2}, \frac{1}{2}$ and $\frac{5}{2}$ (b) $\frac{1}{2}, \frac{-1}{2}$ and $\frac{-5}{2}$

(c) $\frac{-1}{2}, \frac{1}{2}$ and $\frac{3}{2}$ (d) $\frac{1}{2}, \frac{-1}{2}$ and $\frac{-3}{2}$

2. The density of a cube is measured by measuring its mass and the length of its side. If the maximum errors in the measurements of mass and length are 3% and 2% respectively, then the maximum error in the measurement of density is

(a) 7% (b) 5% (c) 9% (d) 3%

3. The velocity of a body moving in viscous medium is given by $V = \frac{P}{Q}(1 - e^{Qt})$ where t is time; P and Q are constants. Then the dimensions of P are

(a) M^0LT^{-2} (b) $M^0L^2T^{-2}$

(c) $M^{-1}LT^{-2}$ (d) $M^0L^0T^{-2}$

4. In the relation, $y = r\sin(\omega t + kx)$, the dimensional formula for kx or ωt is same as

(a) r/ω (b) r/y (c) $\omega t/r$ (d) $yr/\omega t$

5. The dimensional formula for acceleration, velocity and length are $\alpha\beta^{-2}$, $\alpha\beta^{-1}$ and $\alpha\gamma$. What is the dimensional formula for the coefficient of friction?

(a) $\alpha\beta\gamma$ (b) $\alpha^{-1}\beta^0\gamma^0$

(c) $\alpha^0\beta^{-1}\gamma^0$ (d) $\alpha^0\beta^0\gamma^{-1}$

6. Turpentine oil is flowing through a tube of length l and radius r. The pressure difference between the two ends of the tube is P. The viscosity of oil is given by $\eta = \frac{P(r^2 - x^2)}{4vl}$, where v is the velocity of oil at a distance x from the axis of the tube. The dimension of η is

(a) $[M^0L^0T^0]$ (b) $[MLT^{-1}]$

(c) $[ML^2T^{-2}]$ (d) $[ML^{-1}T^{-1}]$

7. The dimensions of mobility of charge carriers are

(a) $M^{-2}T^2A$ (b) $M^{-1}T^2A$

(c) $M^{-2}T^3A$ (d) $M^{-1}T^3A$

8. A physical quantity Q is found to depend on observables x, y and z, obeying relation $Q = \frac{x^3y^2}{z}$. The percentage error in the measurements of x, y and z are 1%, 2% and 4% respectively. What is percentage error in the quantity Q ?

(a) 11% (b) 4% (c) 1% (d) 3%

9. What will be the unit of time in that system in which the unit of length is metre, unit of mass is kg and unit of force is kg wt?

(a) $(9.8)^2$ s (b) 9.8 s

(c) $\sqrt{9.8}$ s (d) $\frac{1}{\sqrt{9.8}}$ s

10. The relation between force F and density d is $F = \frac{x}{\sqrt{d}}$. The dimensions of x are

(a) $[L^{-1/2}M^{3/2}T^{-2}]$ (b) $[L^{-1/2}M^{1/2}T^{-2}]$

(c) $[L^{-1}M^{3/2}T^{-2}]$ (d) $[L^{-1}M^{1/2}T^{-2}]$

11. Which of the following is a dimensionless quantity?

(a) Magnetic flux density (b) Electric flux density

(c) Lumen flux density (d) Optical density.

12. In a vernier callipers, N divisions of vernier scale coincide with $(N - 1)$ division of main scale (in which one division represents 1 mm). The vernier constant is (cm)

(a) N (b) $N - 1$ (c) $\frac{1}{N-1}$ (d) $\frac{1}{10N}$

13. The side of a cubical block when measured with a vernier callipers is 2.50 cm. The vernier constant is 0.01 cm. The maximum possible error in the area of the side of the block is

(a) ± 0.01 cm^2 (b) ± 0.02 cm^2

(c) ± 0.05 cm^2 (d) ± 0.10 cm^2

14. A physical quantity is given by $X = M^aL^bT^c$. The percentage error in measurement of M, L and T are α, β and γ respectively. Then, the maximum % error in the quantity X is

(a) $a\alpha + b\beta + c\gamma$ (b) $a\alpha + b\beta - c\gamma$

(c) $\frac{a}{\alpha} + \frac{b}{\beta} + \frac{c}{\gamma}$ (d) none of these.

15. A certain body weighs 22.42 g and has a measured volume of 4.7cc. The possible error in the measurement of mass and volume are 0.01 g and 0.1 cc. Then maximum error in the density will be

(a) 22% (b) 2% (c) 0.2% (d) 0.02%.

16. In the formula, $X = 3YZ^2$; X has dimensions of capacitance and Z has dimensions of magnetic induction. The dimensions of Y are

(a) $[M^{-3}L^{-2}T^{-2}A^4]$ (b) $[ML^{-2}T^2A^2]$

(c) $[M^{-3}L^{-2}T^4A^4]$ (d) $[M^{-3}L^{-2}T^8A^4]$

17. A new unit of length is chosen such that the speed of light in vacuum is unity. What is the distance between the sun and the earth in terms of the new unit if light takes 8 min and 20 s to cover this distance?

(a) 300 (b) 400 (c) 500 (d) 600

18. Which of the following is the most precise device for measuring length?

(a) A vernier callipers with 20 divisions on the vernier scale coinciding with 19 main scale divisions

(b) A screw gauge of pitch 1 mm and 100 divisions on the circular scale.

(c) A spherometer of pitch 0.1 mm and 100 divisions on the circular scale.

(d) An optical instrument that can measure length to within a wavelength of light.

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19. Which of the following statements is incorrect regarding mass?
(a) It is a basic property of matter
(b) The SI unit of mass is kg
(c) The mass of an atom is expressed in u
(d) It depends upon the temperature, pressure or location of the object in space.

20. Percentage errors in the measurement of mass and speed are 2% and 3% respectively. The error in the estimation of kinetic energy obtained by measuring mass and speed will be
(a) 8% (b) 2% (c) 12% (d) 10%

21. In an experiment to measure the height of a bridge by dropping stone into water underneath, if the error in measurement of time is 0.1 s at the end of 2 s, then the error in estimation of height of bridge will be
(a) 0.49 m (b) 0.98 m (c) 1.96 m (d) 2.11 m

22. If E, m, I and G denote energy, mass, angular momentum and gravitational constant respectively, the quantity (EI^2/m^5G^2) has the dimensions of
(a) angle (b) length (c) mass (d) time

23. In the following equation, x, t and F represent respectively, displacement, time and force :

$$F = a + bt + \frac{1}{c + dx} + A\sin(\omega t + \phi).$$

The dimensional formula for $A \cdot d$ is
(a) T^{-1} (b) L^{-1} (c) M^{-1} (d) TL^{-1}

24. The least count of the metre rod is 0.1 cm. What is the permissible error in the length of the rod measured with it ?
(a) ± 0.2 cm (b) ± 0.1 cm
(c) ± 0.05 cm (d) ± 0.01 cm

25. Which two of the following five physical parameters have the same dimensions ?
1. energy density 2. refractive index
3. dielectric constant 4. young's modulus
(a) 1 and 4 (b) 1 and 5
(c) 2 and 4 (d) 3 and 5

26. In a new system of units, unit of mass is 10 kg, unit of length is 1 km and unit of time is 1 minute. The value of 1 joule in this new hypothetical system is
(a) 3.6×10^{-4} new units (b) 6×10^{7} new units
(c) 10^{11} new units (d) 1.67×10^{4} new units

27. The ratio of the dimensions of Planck constant and that of moment of inertia is the dimensions of
(a) time (b) frequency
(c) angular momentum (d) velocity

28. The dimensions of resistance × capacitance are same as that of
(a) current (b) energy
(c) frequency (d) time-period.

29. Three measurements are made as 18.425 cm, 7.21 cm and 5.0 cm. The sum of measurements upto correct number of significant figures is
(a) 30.635 cm (b) 30.64 cm
(c) 30.63 cm (d) 30.6 cm

30. In an experiment of simple pendulum, the errors in the measurement of length of the pendulum (L) and time period (T) are 3% and 2% respectively. The maximum percentage error in the value of $\frac{L}{T^2}$ is
(a) 5% (b) 7% (c) 8% (d) 1%

31. The moment of inertia of a body rotating about a given axis is 12.0 kgm^2 in the SI system. What is the value of the moment of inertia in a system of units in which the unit of length is 5 cm and the unit of mass is 10 g?
(a) 2.4×10^3 (b) 6.0×10^3
(c) 5.4×10^5 (d) 4.8×10^5

32. In a slide callipers, $(m + 1)$ number of vernier divisions is equal to m number of smallest main scale divisions. If d unit is the magnitude of the smallest main scale division, then the magnitude of the vernier constant is
(a) $\frac{d}{(m+1)}$ unit (b) $\frac{d}{m}$ unit
(c) $\frac{md}{(m+1)}$ unit (d) $\frac{(m+1)d}{m}$ unit

33. The temperatures of two bodies measured by a thermometer are $t_1 = 20°C \pm 0.5°C$ and $t_2 = 50°C \pm 0.5\ °C$. The temperature difference and the error therein is
(a) 30 °C ± 1 °C (b) 70 °C ± 0.5 °C
(c) 30 °C ± 0.5 °C (d) 70 °C ± 1 °C

34. Two resistors of resistances $R_1 = (100 \pm 3)\ \Omega$ and $R_2 = (200 \pm 4)\ \Omega$ are connected in parallel. The equivalent resistance of the parallel combination is
(a) $(66.7 \pm 1.8)\ \Omega$ (b) $(66.7 \pm 4.0)\ \Omega$
(c) $(66.7 \pm 3.0)\ \Omega$ (d) $(66.7 \pm 7.0)\ \Omega$

35. Which of the following statements is incorrect regarding significant figures?
(a) All the non-zero digits are significant.
(b) All the zeros between two non-zero digits are significant.
(c) Greater the number of significant figures in a measurement, smaller is the percentage error.
(d) The power of 10 is counted while counting the number of significant figures.

36. You measure two quantities as A = 1.0 m ± 0.2 m, B = 2.0 m ± 0.2 m. We should report correct value for $\sqrt{AB}$ as
(a) 1.4 m ± 0.4 m (b) 1.41 m ± 0.15 m
(c) 1.4 m ± 0.3 m (d) 1.4 m ± 0.2 m

37. The equation of state of a gas is given by $\left(P + \frac{a}{V^3}\right)(V - b^2) = cT$, where P, V, T are pressure, volume and temperature respectively, and a, b, c are constants. The dimensions of a and b are respectively
(a) ML^8T^{-2} and $L^{3/2}$ (b) ML^5T^{-2} and L^3
(c) ML^5T^{-2} and L^6 (d) ML^6T^{-2} and $L^{3/2}$

38. The time dependence of a physical quantity p is given by $p = p_0 \exp(-\alpha t^2)$, where α is a constant and t is the time. The constant α

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(a) is dimensionless (b) has dimensions $[T^{-2}]$
(c) has dimensions $[T^2]$ (d) has dimensions of p

39. An important milestone in the evolution of the universe just after the Big Bang is the Planck time t_p, the value of which depends on three funda-mental constants-speed of light in vacuum c, Gravitational constant G and Planck's constant h. Then, $t_p \propto$

(a) Ghc^5 (b) $\frac{c^5}{Gh}$ (c) $\frac{Gh}{c^5}$ (d) $\left(\frac{Gh}{c^5}\right)^{1/2}$

40. The mass of a body is 20.0 g and its volume is 10.0 cm^3. If possible maximum errors in the measurement of mass of body and volume of body are 0.001 g and 0.01 cm^3 respectively, then the maximum error in the value of density is

(a) 0.001 g cm^{-3} (b) 0.010 g cm^{-3}
(c) 0.10 g cm^{-3} (d) none of these

41. If 3.8×10^{-6} is added to 4.2×10^{-5} giving due regard to significant figures, then the result will be

(a) 4.58×10^{-5} (b) 4.6×10^{-5}
(c) 4.5×10^{-5} (d) 4.7×10^{-5}

42. When one metre, one kg and one minute are taken as fundamental units, the magnitude of a force is 36 units. What is the value of this force in CGS system?

(a) 10^3 dyne (b) 10^5 dyne
(c) 10^6 dyne (d) 10^7 dyne

43. The dimensions of σb^4 (σ = Stefan's constant and b = Wein's constant) are

(a) $[M^0L^0T^0]$ (b) $[ML^4T^{-3}]$
(c) $[ML^{-2}T]$ (d) $[ML^6T^{-3}]$

44. Which one of the following is dimensionally incorrect?

(a) Capacitance $C = [M^{-1}L^{-2}T^4A^2]$
(b) Magnetic field induction $B = [ML^0T^{-2}A^{-1}]$
(c) Coefficient of self-induction $L = [ML^2T^{-2}A^{-1}]$
(d) Specific resistance $\rho = [ML^3T^{-3}A^{-2}]$

45. A quantity X is given by $\varepsilon_0 L \frac{\Delta V}{\Delta t}$, where ε_0 is the permittivity of free space, L is length, ΔV is potential difference and Δt is time interval. The dimensional formula for X is the same as that of

(a) resistance (b) charge
(c) voltage (d) current

DAY 01 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____
(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (a) : $E = G^p h^q c^r$ ...(i)

Equating dimensions on both sides of equation (i), we get

$[M^1L^2T^{-2}] = [M^{-1}L^3T^{-2}]^p [ML^2T^{-1}]^q [LT^{-1}]^r$

$= [M^{-p+q} L^{3p+2q+r} T^{-2p-q-r}]$

Applying principle of homogeneity of dimensions, we get

$-p + q = 1$ ...(ii)

$3p + 2q + r = 2$ ...(iii)

$-2p - q - r = -2$ ...(iv)

Adding (iii) and (iv), we get

$p + q = 0$ ...(v)

Adding (ii) and (v), we get

$2q = 1$ or $q = \frac{1}{2}$

From (ii), $p = q - 1 = \frac{1}{2} - 1 = -\frac{1}{2}$

Substituting the values of p and q in equation (iii), we get

$-\frac{3}{2} + 1 + r = 2$ or $r = \frac{5}{2}$

Hence, $p = -\frac{1}{2}, q = \frac{1}{2}, r = \frac{5}{2}$

2. (c) : $\because \quad \rho = \frac{M}{L^3}$,

$\therefore \quad \frac{\Delta\rho}{\rho} = \frac{\Delta M}{M} + 3\frac{\Delta L}{L} = 3\% + 3(2\%) = 9\%.$

3. (a) : $V = \frac{P}{Q}(1 - e^{Qt})$

As Qt = number, $\therefore \quad [Q] = \frac{1}{[t]} = T^{-1}$

Now, $\frac{P}{Q} = V$,

$\therefore \quad [P] = [Q \times V] = T^{-1} \times LT^{-1} = [M^0LT^{-2}]$

4. (b) : ωt and kx both are dimensionless. Out of the given options, only r/y is dimensionless.

5. (d) : Here, $[a] = LT^{-2} = \alpha\beta^{-2}$

$[v] = LT^{-1} = \alpha\beta^{-1}$

$\therefore \quad \alpha = L, \beta = T$

$[L] = \alpha\gamma$

$\therefore \quad \gamma = \frac{[L]}{\alpha} = \frac{L}{L} = 1$

Coefficient of friction,

$\mu = \frac{F}{R} = M^0L^0T^0$ *i.e.* dimensionless

Now, $\alpha^0\beta^0\gamma^{-1} = L^0T^0(1)^{-1} = 1$,

which is dimensionless.

6. (d) : Dimensions of $P = [ML^{-1}T^{-2}]$

Dimensions of $r = [L]$

Dimensions of $v = [LT^{-1}]$

Dimensions of $l = [L]$

$\therefore$ Dimensions of $\eta = \frac{[P][(r^2 - x)^2]}{[v][l]} = \frac{[ML^{-1}T^{-2}][L^2]}{[LT^{-1}][L]}$

$= [ML^{-1}T^{-1}]$

7. (b) : Mobility, $\mu = \frac{\text{Drift velocity } (v_d)}{\text{Electric field } (E)}$

$\therefore \quad [\mu] = \frac{[v_d]}{[E]} = \frac{[M^0LT^{-1}]}{[MLT^{-3}A^{-1}]} = [M^{-1}T^2A]$

8. (a) : $Q = \frac{x^3y^2}{z}$

The percentage error in the quantity Q is

$\frac{\Delta Q}{Q} \times 100 = \left(3\frac{\Delta x}{x} + 2\frac{\Delta y}{y} + \frac{\Delta z}{z}\right) \times 100$

$= 3\left(\frac{\Delta x}{x} \times 100\right) + 2\left(\frac{\Delta y}{y} \times 100\right) + \frac{\Delta z}{z} \times 100$

$= 3 \times 1\% + 2 \times 2\% + 4\% = 11\%$

9. (d) : As $[F] = [MLT^{-2}]$

$\therefore \quad T^2 = \frac{ML}{F} = \frac{1\text{ kg} \times 1\text{ m}}{1\text{ kg wt}} = \frac{1\text{ kg} \times 1\text{ m}}{9.8\text{ N}}$

($\because$ 1 kg wt = 9.8 N) or $T = \frac{1}{\sqrt{9.8}}$ s

10. (a) : Given : $F = \frac{x}{\sqrt{d}}$

$\therefore \quad x = F\sqrt{d}$

$[x] = [L^1\,M^1\,T^{-2}][L^{-3}\,M^1\,T^0]^{1/2}$

$= [L^1\,M^1\,T^{-2}][L^{-3/2}\,M^{1/2}\,T^0] = [L^{-1/2}\,M^{3/2}\,T^{-2}]$

11. (d) : Optical density is the ratio of the speed of light in two media. As optical density is the ratio of two similar physical quantities, therefore it is the dimensionless quantity. All other given physical quantities have dimensions.

12. (d) : N VSD = $(N - 1)$ MSD

1 VSD $= \frac{N-1}{N}$ MSD

V.C. = 1 MSD – 1 VSD

$= 1 \text{ MSD} - \left(\frac{N-1}{N}\right)\text{MSD} = \frac{1}{N}\text{ MSD}$

$= \frac{1}{N}\text{ mm} = \frac{1}{10N}\text{ cm}$

13. (c) : Here $l = 2.50$ cm and $\Delta l = 0.01$ cm

Since $A = l^2 = (2.50\text{ cm})^2$

$\therefore \quad \frac{\Delta A}{A} = 2 \cdot \frac{\Delta l}{l}; \quad \frac{\Delta A}{A} = 2 \times \frac{0.01\text{ cm}}{2.50\text{ cm}}$

$\therefore \quad \Delta A = \frac{2 \times 0.01\text{ cm}}{2.50\text{ cm}} \times (2.50\text{ cm})^2$

$= 2 \times 0.01 \times 2.50\text{ cm}^2 = 0.01 \times 5\text{ cm}^2$

or $\Delta A = \pm 0.05\text{ cm}^2$

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14. (a) : $X = M^aL^bT^c$

Percentage error in X

$$\frac{\Delta X}{X}\times 100 = a\frac{\Delta M}{M}\times 100 + b\frac{\Delta L}{L}\times 100 + c\frac{\Delta T}{T}\times 100$$ As given,

$$\frac{\Delta M}{M}\times 100 = \alpha,\quad \frac{\Delta L}{L}\times 100 = \beta,\quad \frac{\Delta T}{T}\times 100 = \gamma$$

$\therefore$ Percentage error in $X = a\alpha + b\beta + c\gamma$.

15. (b) : Density $\rho = \dfrac{\text{mass } m}{\text{volume } V}$ ...(i)

Take logarithm on the both sides of eqn. (i), we get

$\ln\rho = \ln m - \ln V$ ...(ii)

Differentiate eqn. (ii), on both sides, we get

$$\frac{\Delta\rho}{\rho} = \frac{\Delta m}{m} - \frac{\Delta V}{V}$$

Errors are always added for maximum error.

$\therefore$ Maximum error in the density ρ will be

$$= \left[\frac{\Delta m}{m} + \frac{\Delta V}{V}\right]\times 100\,\% = \left[\frac{0.01}{22.42} + \frac{0.1}{4.7}\right]\times 100\,\% = 2\%$$

16. (d) : As $q = CV$,

$$\Rightarrow\ C = \frac{q}{V} = \frac{q^2}{W}\quad \left[\text{as } V = \frac{W}{q}\right]$$

$$[X]\rightarrow[C] = \left[\frac{A^2T^2}{ML^2T^{-2}}\right] = [M^{-1}L^{-2}T^4A^2]$$

$$F = BIl\sin\theta,\ [B] = \left[\frac{F}{Il}\right]$$

$$[Z]\rightarrow[B] = \left[\frac{MLT^{-2}}{AL}\right] = [ML^0T^{-2}A^{-1}]$$

Given: $X = 3YZ^2 \Rightarrow Y = X/(3Z^2)$

$$\text{or}\quad [Y] = \frac{[X]}{[Z^2]} = \frac{[M^{-1}L^{-2}T^4A^2]}{[ML^0T^{-2}A^{-1}]^2} = [M^{-3}L^{-2}T^8A^4]$$

17. (c) : Here,

Speed of light in vacuum,

c = 1 new unit of length s^{-1}

Time taken by light of sun to reach the earth

t = 8 min and 20 seconds

$= (8\times 60 + 20)$ s = 500 s

$\therefore$ Distance between the sun and the earth

$S = ct$ = 1 new unit of length $s^{-1}\times 500$ s

= 500 new unit of length

18. (d) : The most precise device is one whose least count is the least.

(a) Least count of vernier callipers

$$= 1\text{ MSD} - 1\text{ VSD} = 1\text{ MSD} - \frac{19}{20}\text{ MSD}$$

$$= \frac{1}{20}\text{MSD} = \frac{1}{20}\text{ mm} = \frac{1}{200}\text{ cm} = 0.005\text{ cm}$$

($\because$ 1 MSD = 1 mm)

(b) Least count of screw gauge

$$= \frac{\text{Pitch}}{\text{No.of divisions on circular scale}}$$

$$= \frac{1}{100}\text{mm} = \frac{1}{1000}\text{cm} = 0.001\text{ cm}$$

(c) Least count of spherometer

$$= \frac{\text{Pitch}}{\text{No.of divisions on circular scale}}$$

$$= \frac{0.1\text{ mm}}{100} = \frac{1}{1000}\text{ mm} = 0.0001\text{ cm}$$

(d) Wavelength of light, $\lambda \approx 10^{-5}$ cm = 0.00001 cm

Clearly the optical instrument is the most precise.

19. (d) : Mass does not depend on the temperature, pressure or location of the object in space.

20. (a) : As $K = \frac{1}{2}mv^2$

$$\therefore\quad \frac{\Delta K}{K}\times 100 = \frac{\Delta m}{m}\times 100 + \frac{2\Delta v}{v}\times 100 = 2\% + 2\times 3\% = 8\%$$

21. (c) : $h = ut + \frac{1}{2}gt^2$

$$h = 0 + \frac{1}{2}\times 9.8\,(2)^2 = 19.6\text{ m}\qquad (\because\ u = 0)$$

$$\frac{\Delta h}{h} = 2\left(\frac{\Delta t}{t}\right) = 2\left(\frac{0.1}{2}\right) = \frac{1}{10}$$

$$\Delta h = \frac{h}{10} = \frac{19.6}{10} = 1.96\text{ m}$$

22. (a) : $[E] = [ML^2T^{-2}]$, $[m] = [M]$, $[l] = [ML^2T^{-1}]$,

$[G] = [M^{-1}L^3T^{-2}]$

$$\therefore\quad \left[\frac{El^2}{m^5G^2}\right] = \frac{[ML^2T^{-2}]\cdot[M^2L^4T^{-2}]}{[M^5]\cdot[M^{-2}L^6T^{-4}]} = [M^0L^0T^0]$$

As angle has no dimension, this has the same dimension as the angle.

23. (b) : $F = a + bt + \dfrac{1}{c + dx} + A\sin(\omega t + \phi)$

As $\sin(\omega t + \phi)$ is dimensionless, therefore A has dimensions of force.

$\therefore$ $[A] = [F] = [MLT^{-2}]$

As each term on RHS represents force

$$\therefore\quad \left[\frac{1}{c + dx}\right] = [F]$$

$$\left[\frac{1}{c}\right] = [F]$$

$$\therefore\quad [c] = \frac{1}{[F]} = \frac{1}{[MLT^{-2}]} = [M^{-1}L^{-1}T^2]$$

As c is added to dx, therefore dimensions of c is same that of dx.

$\therefore$ $[dx] = [c]$

$$\text{or}\quad [d] = \frac{[c]}{[x]} = \frac{[M^{-1}L^{-1}T^{-2}]}{[L]} = [M^{-1}L^{-2}T^{-2}]$$

The dimensional formula for $A\cdot d$ is

$$[A\cdot d] = [MLT^2][M^{-1}L^{-2}T^{-2}] = [L^{-1}]$$

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24. (b) : Permissible error = ± least count = ± 0.1 cm

25. (a) : $[\text{Energy density}] = \left[\frac{\text{Work done}}{\text{Volume}}\right]$

$$= \frac{[MLT^{-2}L]}{[L^3]} = [ML^{-1}T^{-2}]$$

$$[\text{Young's modulus}] = [Y] = \left[\frac{\text{Force}}{\text{Area}}\right] \times \frac{[l]}{[\Delta l]}$$

$$= \frac{[MLT^{-2}]}{[L^2]} \frac{[L]}{[L]} = [ML^{-1}T^{-2}]$$

The dimensions of 1 and 4 are the same.

26. (a) : The dimensional formula of energy is $[ML^2T^{-2}]$.

$$n_2 = 1\left[\frac{1\,\text{kg}}{10\,\text{kg}}\right]^1\left[\frac{1\,\text{m}}{1\,\text{km}}\right]^2\left[\frac{1\,\text{s}}{1\,\text{min}}\right]^{-2}$$

$$= \frac{1}{10} \times \frac{1}{10^6} \times \frac{1}{(60)^{-2}} = \frac{3600}{10^7} = 3.6 \times 10^{-4}$$

27. (b) : Planck's constant, $h = \frac{E}{\upsilon}$

$$= \frac{[ML^2T^{-2}]}{[T^{-1}]} = [ML^2T^{-1}]$$

Moment of inertia, $I = [ML^2]$

$$\frac{h}{I} = \frac{[ML^2T^{-1}]}{[ML^2]} = [T^{-1}] = \text{frequency}$$

28. (d) : Resistance = $\frac{\text{voltage}}{\text{current}}$ and

$$\text{Capacitance} = \frac{\text{charge}}{\text{voltage}}$$

∴ Resistance × capacitance

$$= \frac{\text{voltage}}{\text{current}} \times \frac{\text{charge}}{\text{voltage}} = \frac{\text{charge}}{\text{current}}$$

$$= \frac{\text{current} \times \text{time period}}{\text{current}} = \text{time period.}$$

29. (d) : Sum of the measurements is correct only upto one place of decimal corresponding to the number with least decimal places.

$$18.425 + 7.21 + 5.0 = 30.635 = 30.6 \text{ cm}$$

30. (b) : Time period of simple pendulum is

$$T = 2\pi\sqrt{\frac{L}{g}}$$

Squaring both sides, we get

$$\therefore\ T^2 = 4\pi^2\frac{L}{g} \qquad \ldots(i)$$

$$\text{or}\quad g = 4\pi^2\frac{L}{T^2}$$

The maximum percentage error in g is

$$\frac{\Delta g}{g} \times 100 = \frac{\Delta L}{L} \times 100 + 2\left(\frac{\Delta T}{T}\right) \times 100 = 3\% + 2 \times 2\% = 7\%$$

From (i), we get $\frac{L}{T^2} = \frac{g}{4\pi^2}$

The maximum percentage error in $\frac{L}{T^2}$ is

$$\frac{\Delta\left(\frac{L}{T^2}\right)}{\frac{L}{T^2}} \times 100 = \frac{\Delta g}{g} \times 100 = 7\%$$

31. (d) : $n_2 = n_1\left(\frac{M_1}{M_2}\right)^a\left(\frac{L_1}{L_2}\right)^b\left(\frac{T_1}{T_2}\right)^c$ ...(i)

Dimensional formula of moment of inertia = $[ML^2T^0]$

∴ $a = 1, b = 2, c = 0$

Here, $I_1 = 12.0$, $M_1 = 1$ kg, $M_2 = 10$ g

$L_1 = 1$ m, $L_2 = 5$ cm, $T_1 = 1$ s, $T_2 = 1$ s

$$I_2 = 12.0\left(\frac{1\,\text{kg}}{10\,\text{g}}\right)^1\left(\frac{1\,\text{m}}{5\,\text{cm}}\right)^2\left(\frac{1\,\text{s}}{1\,\text{s}}\right)^0 \qquad \text{(Using (i))}$$

$$= 12 \times \left(\frac{1000\,\text{g}}{10\,\text{g}}\right)^1\left(\frac{100\,\text{cm}}{5\,\text{cm}}\right)^2 \times 1$$

$$= 12 \times 100 \times 400 = 4.8 \times 10^5$$

32. (a) : $(m + 1)$ V.S.D. = m M.S.D.

$$1\ \text{V.S.D.} = \frac{m}{m+1}\ \text{M.S.D.}$$

Vernier constant = 1 M.S.D. – 1 V.S.D.

$$= 1\,\text{M.S.D.} - \left(\frac{m}{m+1}\right)\text{M.S.D.}$$

$$= \frac{1}{(m+1)}\,\text{M.S.D.} = \frac{d}{m+1}\ \text{unit}$$

33. (a) : Here, $t_1 = 20\ ^\circ\text{C} \pm 0.5\ ^\circ\text{C}$

$t_2 = 50\ ^\circ\text{C} \pm 0.5\ ^\circ\text{C}$

The temperature difference of two bodies is

$t = t_2 - t_1 = 50\ ^\circ\text{C} - 20\ ^\circ\text{C} = 30\ ^\circ\text{C}$

The error in temperature difference is given by

$\Delta t = (\Delta t_1 + \Delta t_2)$

$= (0.5\ ^\circ\text{C} + 0.5\ ^\circ\text{C}) = 1\ ^\circ\text{C}$

∴ The temperature difference is $30\ ^\circ\text{C} \pm 1\ ^\circ\text{C}$.

34. (a) : Here, $R_1 = (100 \pm 3)\ \Omega$

$R_2 = (200 \pm 4)\ \Omega$

The equivalent resistance in parallel combination is

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R_p} = \frac{1}{100} + \frac{1}{200} = \frac{3}{200}$$

$$R_p = \frac{200}{3} = 66.7\ \Omega$$

The error in equivalent resistance is given by

$$\frac{\Delta R_p}{R_p^2} = \frac{\Delta R_1}{R_1^2} + \frac{\Delta R_2}{R_2^2}$$

$$\Delta R_p = \Delta R_1\left(\frac{R_p}{R_1}\right)^2 + \Delta R_2\left(\frac{R_p}{R_2}\right)^2$$

$$= 3\left(\frac{66.7}{100}\right)^2 + 4\left(\frac{66.7}{200}\right)^2 = 1.8\ \Omega$$

Hence, the equivalent resistance along with error in parallel combination is $(66.7 \pm 1.8)\ \Omega$.

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35. (d) : The power of 10 is irrelevant to the determination of significant figures.

36. (c) : If u_1 and u_2 be the units to measure a quantity Q and n_1, n_2 be the numerical values respectively then we know that $Q = n_1u_1 = n_2u_2$. Since the quantity Q does not change irrespective of the units used to measure it Q = constant. So nu = constant $\Rightarrow n \propto \frac{1}{u}$ *i.e.* smaller the unit of measurement, greater is the corresponding numerical value.

37. (a) : Given, $\left(P + \frac{a}{V^3}\right)(V - b^2) = cT$

Dimensions of $[a]$ = dimensions of $[PV^3]$

$$= \left[\frac{F}{A}V^3\right] \qquad \left(\because\ P = \frac{F}{A}\right)$$

$$= \frac{[MLT^{-2}]}{[L^2]} \times [L^3]^3 = [ML^8T^{-2}]$$

Now, dimensions of $[b]^2$ = dimensions of $[V]$

$[b] = [L^3]^{1/2}$ or $[b] = [L^{3/2}]$

38. (b) : Given : $p = p_0e^{-\alpha t^2}$

αt^2 is dimensionless

$$\therefore \quad [\alpha] = \frac{1}{[t^2]} = \frac{1}{[T^2]} = [T^{-2}]$$

39. (d) : $[Gh] = [M^{-1}L^3T^{-2}][ML^2T^{-1}] = [M^0L^5T^{-3}]$

$[c] = [LT^{-1}]$

$$\therefore \quad \left[\frac{Gh}{c^5}\right]^{1/2} = [T]$$

Hence, $t_p \propto \left(\frac{Gh}{c^5}\right)^{1/2} \qquad (\because\ [t_p] = [T])$

40. (d) : Maximum error in measuring mass is 0.001 g, and maximum error in measuring volume is 0.01 cm^3.

$$\frac{\Delta\rho}{\rho} = \frac{\Delta M}{M} + \frac{\Delta V}{V} = \frac{0.001}{20.0} + \frac{0.01}{10.0}$$

$$= (5 \times 10^{-5}) + (1 \times 10^{-3}) = 1.05 \times 10^{-3}$$

$$\Delta\rho = (1.05 \times 10^{-3}) \times \rho$$

$$= 1.05 \times 10^{-3} \times \frac{20.0}{10.0} = 0.002 \text{ g cm}^{-3}$$

41. (b) : We will use the general rule of addition by making the powers same.

i.e., we add 3.8×10^{-6} and 42×10^{-6}, we get

$45.8 \times 10^{-6} = 4.58 \times 10^{-5}$.

As least number of significant figures in given values are 2, so we round off the result to 4.6×10^{-5}.

42. (a) : $n_2 = n_1\left[\frac{M_1}{M_2}\right]^a\left[\frac{L_1}{L_2}\right]^b\left[\frac{T_1}{T_2}\right]^c$

$M_1 = 1$ kg $\quad M_2 = 1$ g

$L_1 = 1$ m $\quad L_2 = 1$ cm

$T_1 = 1$ min $\quad T_2 = 1$ s

$n_1 = 36 \quad n_2 = ?$

The dimensional formula of force is $[MLT^{-2}]$.

$\therefore \quad a = 1, b = 1, c = -2$

$$n_2 = 36\left[\frac{1\text{ kg}}{1\text{ g}}\right]^1\left[\frac{1\text{ m}}{1\text{ cm}}\right]^1\left[\frac{1\text{ min}}{1\text{ s}}\right]^{-2}$$

$$= 36\left[\frac{1000\text{ g}}{\text{g}}\right]^1\left[\frac{100\text{ cm}}{1\text{ cm}}\right]^1\left[\frac{60\text{ s}}{1\text{ s}}\right]^{-2}$$

$$= \frac{36 \times 10^3 \times 10^2}{3600} = 10^3$$

Hence, in the CGS system of units the value of given force is 10^3 dyne.

43. (b) : Wein's displacement law

$\lambda_m T = b$ or $b^4 = \lambda_m^4 T^4$ ...(i)

From Stefan's law,

$$\sigma = \frac{E}{AtT^4} \qquad \text{...(ii)}$$

From (i) and (ii),

$$\sigma b^4 = \frac{E\lambda_m^4 T^4}{AtT^4}$$

$$[\sigma b^4] = \frac{[ML^2T^{-2}][L]^4}{[L^2][T]} = [ML^4T^{-3}]$$

44. (c) : $[C] = \frac{[q^2]}{[W]} = \frac{[AT]^2}{[ML^2T^{-2}]} = [M^{-1}L^{-2}T^4A^2]$

$$[B] = \frac{[F]}{[I][l]} = \frac{[MLT^{-2}]}{[A][L]} = [ML^0T^{-2}A^{-1}]$$

$$[L] = \frac{\varepsilon}{\left(\frac{di}{dt}\right)} = \frac{\left[\frac{W}{q}\right][t]}{[i]} = \left[\frac{ML^2T^{-2}}{AT}\right]\frac{[T]}{[A]}$$

$$= [ML^2T^{-2}A^{-2}]$$

$$[\rho] = \frac{[R][A]}{[L]} = \frac{[ML^2T^{-3}A^{-2}][L^2]}{[L]} = [ML^3T^{-3}A^{-2}]$$

Choice (c) is dimensionally wrong.

45. (d) : As, $C = \frac{\Delta q}{\Delta V}$

or $\varepsilon_0\frac{A}{L} = \frac{\Delta q}{\Delta V} \qquad \left(\because\ C = \frac{\varepsilon_0 A}{L}\right)$

or $\varepsilon_0 = \frac{(\Delta q)L}{A(\Delta V)}$ ...(i)

$$X = \varepsilon_0 L\frac{\Delta V}{\Delta t} \quad \text{(Given)}$$

$$\therefore \quad X = \frac{(\Delta q)L}{A(\Delta V)}L\frac{\Delta V}{\Delta t} \qquad \text{(Using (i))}$$

But $[A] = [L]^2$

$$\therefore \quad X = \frac{\Delta q}{\Delta t} = \text{current}$$

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Motion in a Straight Line

Frame of Reference

Motion of an object is the change in its position with respect to time generally, a three dimensional coordinate system consisting of three mutually perpendicular axes, x, y and z is used to describe motion. The point at which all the three axes meet is the origin and this point serves as the reference point to find the position of an object.

The three dimensional coordinate system along with a clock to measure time is known as frame of reference. If the value of any coordinate of the three coordinates x, y and z of an objet changes with respect to time than the object is considered to be in motion.

Frame of reference can be of two types

- **Intertial frame of reference :** In this Newton's first law of motion holds good.
- **Non intertial frame of reference :** In this Newton's first law of motion does not hold good.

Motion in a Straight Line

To describe motion along a straight line one can choose an axis, say x-axis, so that it coincide with the path of the object. Then one can measure the position of the object with reference to a conveniently chosen origin. Positions to the right of origin is taken as positive and left of origin is taken as negative.

Distance and Displacement

Distance is a measure of the length of the path taken during the change in position of an object. It is a scalar quantity.

Displacement is a measure of the change in position of an object. It is a vector quantity. SI unit of distance and displacement is metre (m).

Position-Time Graph

- The motion of an object can be graphically represented by position time graph. Position time graph of a stationary object is as shown in figure (i).

Figure (i)

- If an object is travelling equal distance inequal intervals of time, then it is said to be in uniform motion. The position-time graph of an object undergoing uniform motion is as shown in figure (ii).

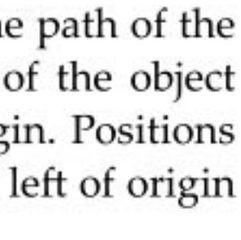

Figure (ii)

- If an object is travelling unequal distance in equal intervals of time or vice versa, the object is said to be in non-uniform motion. The position-time graph for an object undergoing non uniform motion is as shown in figure (iii).

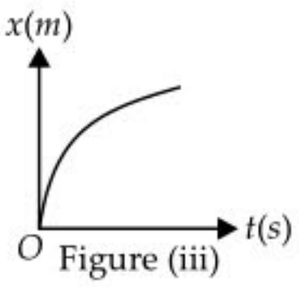

Figure (iii)

Speed

Speed of an object in motion is the ratio of total path length to the corresponding time taken by the object.

$$\text{Speed} = \frac{\text{total path length}}{\text{time taken}}$$

Uniform speed : An object is said to be moving with uniform speed, if it covers equal distances in equal intervals of time.

Average speed : It is the ratio of the total distance travelled by the body to the total time taken

$$\text{Average speed} = \frac{\text{total distance travelled}}{\text{total time taken}}$$

Instantaneous speed : It is the speed of an object at a given instant of time.

Velocity

Velocity of an object is the ratio of displacement and the corresponding time interval taken by the object

$$\text{Velocity} = \frac{\text{displacement}}{\text{time taken}}$$

It is a vector quatity. SI unit of velocity is m s^{-1}. Its dimensional formula is $[M^0L^1T^{-1}]$.

Uniform velocity : An object is said to be moving with uniform velocity, if it undergoes equal displacements in equal intervals of time, however small these intervals may be.

Instantaneous velocity : The velocity of an object at any given instant of time is known as instantaneous velocity.

$$\text{Instantaneous velocity} = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t}$$

Average velocity : It is the ratio of displacement to the time interval for which the motion takes place.

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$$\text{Average velocity} = \frac{\text{displacement}}{\text{time taken}}$$

Acceleration

Acceleration of an object in motion is defined as the ratio of change in velocity and the corresponding time taken by the object

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$$

It is a vector quantity SI unit of acceleration is m s^{-2}. Its dimensional formula is $[M^0L^1T^{-2}]$.

Uniform acceleration : An object is said to be moving with a uniform acceleration if its velocity changes by equal amounts in equal interval of time.

Average acceleration : It is the ratio of total change in velocity of the object during motion to the total time taken.

Instantaneous acceleration : The acceleration of the object at a given instant of time is called its instantaneous acceleration.

$$\text{Instantaneous accleration} = \lim_{\Delta t \to 0} \frac{\Delta V}{\Delta t}$$

Equations of motion for a uniformly accelerated motion

- $v = u + at$
- $s = ut + \frac{1}{2}at^2$
- $v^2 - u^2 = 2as$
- $s_n = u + \frac{a}{2}(2n - 1)$

where u = initial velocity
v = final velocity
s = distance travelled
t = time taken
a = uniform acceleration

and s_n = the distance covered in n^{th} second.

These equations are not valid if the acceleration is non uniform. In case of equation of an object under gravity, acceleration a is replaced by g, acceleration due to gravity.

Velocity-time graph for an accelerated motion

- When an object is moving with zero acceleration, that is with constant velocity, the velocity-time graph is a straight line as shown in figure (i).

Figure (i)

- When an object is moving with constantpositive acceleration, having zero initial velocity, its velocity graph is a straight line as shown in figure (ii).

Figure (ii)

- When an object is moving with positiveconstant acceleration with some initial velocity, the velocity-time graph is straight line as shown in figure (iii).

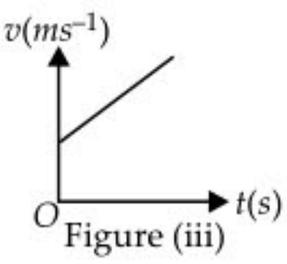

Figure (iii)

- When an object is moving with increasingacceleration, having zero initial velocity, the velocity-time graph is a curve as shown in figure (iv).

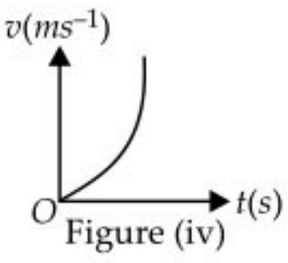

Figure (iv)

- When an object is moving with constantnegative acceleration having positive initial velocity, then velocity time graph is a straight line is as shown in figure (v).

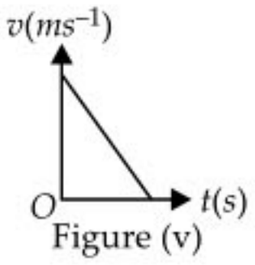

Figure (v)

Position-time graph for accelerated motion

- When and object is moving with uniform positive acceleration, position-time graph is a curve as shown in figure (i).

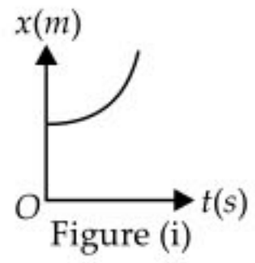

Figure (i)

- When an object is moving with negative acceleration, then position-time graph is a curve as shown in figure (ii).

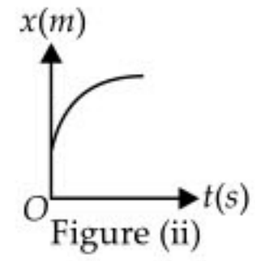

Figure (ii)

- When an object is moving with negative acceleration, then position-time graph is a straight line as shown in figure (iii).

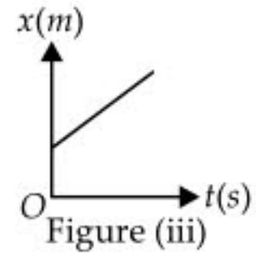

Figure (iii)

Elementary concept of differentiation and integration for describing motion

If an object moving with velocity v along a straight line, the velocity at a time t is given by

$$v = \frac{dx}{dt}$$

where dx is the displacement of the object

If an object is moving in a straight line with uniform acceleration, then

$$a = \frac{dv}{dt}$$

where dv is the change in acceleration in time dt.

Also distance travelled by a particle

$$x = \int v\, dt$$

Velocity of a particle,

$$v = \int a\, dt$$

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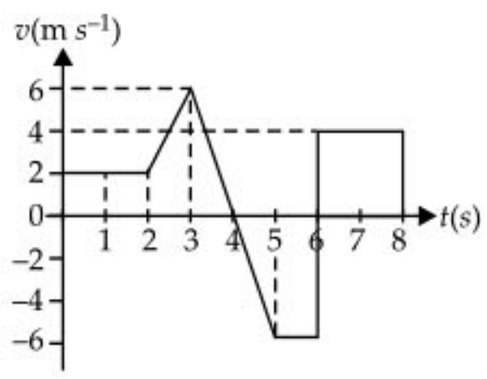
EXAM DRILL

1. A person walks up a stationary escalator in time t_1. If he remains stationary on the escalator, then it can take him up in time t_2. How much time would it take him to walk up the moving escalator?

(a) $\frac{t_1+t_2}{2}$ (b) $\sqrt{t_1t_2}$

(c) $\frac{t_1t_2}{t_1+t_2}$ (d) t_1+t_2

2. The velocity-time graph of a body is shown in figure. The displacement covered by the body in 8 s is



(a) 9 m
(b) 12 m
(c) 10 m
(d) 28 m

3. A streamer moves with velocity 3 km h^{-1} in and against the direction of river water whose velocity is 2 km h^{-1}. Calculate its total time for total journey if the boat travels 2 km in direction of the stream and then back to his place.

(a) 2 h (b) 2.5 h
(c) 2.4 h (d) 3 h

4. A boy of mass 50 kg is standing on a weighing machine placed on the floor of a lift. The machine reads his weight in N. What is the reading of the machine if the lift is moving upwards with a uniform speed of 10 m s^{-1}? (Take $g = 10$ m s^{-2})

(a) 510 N (b) 480 N
(c) 490 N (d) 500 N

5. A particle is projected vertically upwards from a point A on the ground. It takes time t_1 to reach a point B, but it still continues to move up. If it takes further time t_2 to reach the ground from point B. Then height of point B from the ground is

(a) $\frac{1}{2}g(t_1+t_2)^2$ (b) gt_1t_2

(c) $\frac{1}{8}g(t_1+t_2)^2$ (d) $\frac{1}{2}gt_1t_2$

6. A car accelerates from rest at a constant rate α for some time, after which it decelerates at a constant rate β to come to rest. If the total time elapsed is t the maximum velocity acquired by the car is

(a) $\frac{(\alpha^2+\beta^2)t}{\alpha\beta}$ (b) $\frac{\alpha\beta}{t(\alpha+\beta)}$

(c) $\frac{\alpha\beta t}{(\alpha+\beta)}$ (d) $\frac{(\alpha+\beta)t}{\alpha\beta}$

7. Two particles move in the same straight line starting from the same position. The first moves with constant velocity u and the second with constant acceleration f. During the time elapses before the second catches the first greatest distance between the particles is

(a) $\frac{u}{f}$ (b) $\frac{u^2}{2f}$

(c) $\frac{f}{2u^2}$ (d) $\frac{f}{u^2}$

8. A body falling from a high minaret travels 40 m in the last 2 s of its fall to ground. Height of minaret is [Take $g = 10$ m s^{-2}]

(a) 60 m (b) 45 m
(c) 80 m (d) 50 m

9. A particle moves in xy plane according to the law $x = 4\sin 6t$ and $y = 4(1 - \cos 6t)$. The distance traversed by the particle in 4 s is (x and y are in metres)

(a) 96 m (b) 48 m
(c) 24 m (d) 108 m

10. A stone falls freely from rest and the total distance covered by it in the last second of its motion equals the distance covered by it in the first three seconds of its motion. The stone remains in the air for

(a) 6 s (b) 5 s
(c) 7 s (d) 4 s

11. A body is fired vertically upwards. At half the maximum height, the velocity of the body is 10 m s^{-1}. The maximum height raised by the body is (Take $g = 10$ m s^{-2})

(a) 5 m (b) 10 m
(c) 15 m (d) 20 m

12. A particle moves along a straight line OX. At a time t (in seconds) the distance x (in metres) of the particle from O is given by $x = 40 + 12t - t^3$
How long would the particle travel before coming to rest?

(a) 24 m (b) 40 m
(c) 12 m (d) 16 m

13. A drunkard walking in a narrow lane takes 8 steps forward and 6 steps backward, followed again by 8 steps forward and 6 steps backward and so on. Each step is 1 m long and requires 1 s. Determine how long the drunkard takes to fall in a pit 18 m away from the start.

(a) 18 s (b) 126 s
(c) 78 s (d) 62 s

14. A ball A is thrown up vertically with a speed u and at the same instant another ball B is released from a height h. At time t, the speed of A relative to B is

(a) u (b) $2u$
(c) $u - gt$ (d) $\sqrt{u^2 - gt}$

15. A car covers the first one-third of a distance x at a speed of 10 km h^{-1}, the second one-third at a speed of 20 km h^{-1} and the last one-third at a speed of

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60 km h^{-1}. Find the average speed of the car over the entire distance x.
(a) 10 km h^{-1} (b) 12 km h^{-1}
(c) 18 km h^{-1} (d) 20 km h^{-1}

16. From the top of a tower, a particle is thrown vertically downwards with a velocity of 10 m s^{-1}. The ratio of distances covered by it in the 3rd and 2nd seconds of the motion is (Take $g = 10$ m s^{-2})
(a) 5 : 7 (b) 7 : 5
(c) 3 : 6 (d) 6 : 3

17. The distance x covered by a particle varies with time t as $x^2 = 2t^2 + 6t + 1$. Its acceleration varies with x as
(a) x (b) x^2
(c) x^{-1} (d) x^{-3}

18. The position x of a particle with respect to time t along x-axis is given by $x = 9t^2 - t^3$, where x is in metre and t in second. What will be the position of this particle when it achieves maximum speed along the $+x$ direction?
(a) 32 m (b) 54 m
(c) 81 m (d) 24 m

19. A parachutist after bailing out falls 50 m without friction. When parachute opens, it decelerates at 2 m s^{-2}. He reaches the ground with a speed of 3 m s^{-1}. At what height, did he bail out?
(a) 91 m (b) 182 m
(c) 293 m (d) 111 m

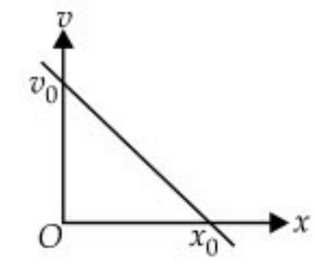
20. You drive a car at a speed of 70 km h^{-1} in a straight road for 8.4 km and then the car runs out of petrol. You walk for 30 min to reach a petrol pump at a distance of 2 km. The average velocity from the beginning of your drive till you reach the petrol pump is
(a) 16.8 km h^{-1} (b) 35 km h^{-1}
(c) 64 km h^{-1} (d) 18.6 km h^{-1}

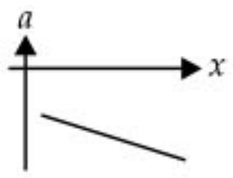
21. Three different objects of masses m_1, m_2 and m_3 are allowed to fall from rest and from the same point O along three different frictionless paths. The speeds of the three objects on reaching the ground will be in the ratio of
(a) $m_1 : m_2 : m_3$ (b) $m_1 : 2m_2 : 3m_3$
(c) 1 : 1 : 1 (d) $\frac{1}{m_1} : \frac{1}{m_2} : \frac{1}{m_3}$

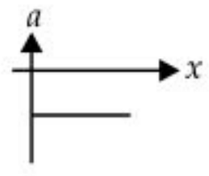
22. A body starts from rest with a uniform acceleration of 2 m s^{-2} for 10 s, it moves with constant speed for 30 s then declerates by 4 m s^{-2} to zero. What is the distance covered by the body?
(a) 750 m (b) 850 m
(c) 600 m (d) 950 m

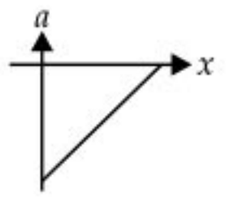
23. A man on the railway platform is just 9 m behind the entrance door of a train, when the train begins to move with a uniform acceleration of 2 m s^{-2} starting from rest. The man immediately picks up a uniform speed to get into the train and he just boards the train. Find the speed he picks up.
(a) 4 m s^{-1} (b) 5 m s^{-1}
(c) 6 m s^{-1} (d) 7 m s^{-1}

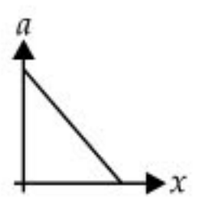
24. Which of the following acceleration-distance graphs corresponds to the velocity-distance graph shown in figure.



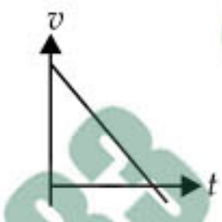
(a) 

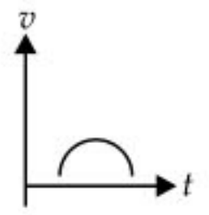
(b) 

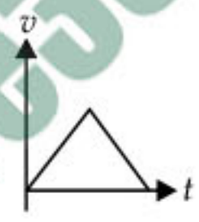
(c) 

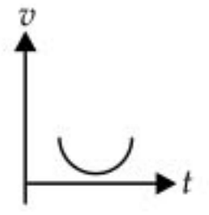
(d) 

25. A particle is thrown upward, then correct v-t graph will be

(a) 

(b) 

(c) 

(d) 

26. A man throws balls with the same speed vertically upwards one after the other at an interval of 2s. What should be the speed of the throw so that more than two balls are in the sky at any time?
(Given g = 9.8 m s^{-2})
(a) Any speed less than 19.6 m s^{-1}
(b) Only with speed 19.6 m s^{-1}
(c) More than 19.6 m s^{-1}
(d) At least 9.8 m s^{-1}

27. A particle initially at rest moves along the x-axis. Its acceleration a varies with time as $a = 4t$. If it starts from the origin, the distance covered by it in 3 second is
(a) 12 m (b) 18 m
(c) 24 m (d) 36 m

28. A ball is dropped on to the floor from a height of 10 m. It rebounds to a height of 2.5 m. If the ball is in contact with the floor for 0.01 seconds, what is the average acceleration during contact?
(Take g = 10 m s^{-2})
(a) 700 m s^{-2} (b) 1400 m s^{-2}
(c) 2100 m s^{-2} (d) 2800 m s^{-2}

29. A particle moving with uniform acceleration has average velocities v_1, v_2 and v_3 over the successive intervals of time t_1, t_2 and t_3 respectively. The value of $(v_1 - v_2)/(v_2 - v_3)$ will be
(a) $\frac{t_1 - t_2}{t_2 - t_3}$ (b) $\frac{t_1 - t_2}{t_2 + t_3}$
(c) $\frac{t_1 + t_2}{t_2 - t_3}$ (d) $\frac{t_1 + t_2}{t_2 + t_3}$

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30. Velocity-time equation of a particle moving in a straight line is $v = 2t - 4$ for $t \leq 2$ s and $v = 4 - 2t$ for $t > 2$ s. The distance travelled by the particle in the time interval from $t = 0$ to $t = 4$ s is

(a) 12 m (b) 16 m
(c) 4 m (d) 8 m

31. Two particles, one with constant velocity 50 m s^{-1} and the other with uniform acceleration 10 m s^{-2}, start moving simultaneously from the same place in the same direction. They will be at a distance of 125 m from each other after

(a) 5 (b) $5(1+\sqrt{2})$
(c) 10 (d) $10(\sqrt{2}+1)$

32. A body of mass m moving along a straight line covers half the distance with a speed of 2 m s^{-1}. The remaining half of the distance is covered in two equal time intervals with a speed of 3 m s^{-1} and 5 m s^{-1} respectively. The average speed of the particle for the entire journey is

(a) $\frac{3}{8}$ m s^{-1} (b) $\frac{8}{3}$ m s^{-1}
(c) $\frac{4}{3}$ m s^{-1} (d) $\frac{16}{3}$ m s^{-1}

33. A man throws a ball vertically upward and it rises through 20 m and returns to his hands. What was the initial velocity (u) of the ball and how much time (T) is remained in the air? (Take $g = 10$ m s^{-2})

(a) $u = 10$ m s^{-1}, $T = 2$ s
(b) $u = 10$ m s^{-1}, $T = 4$ s
(c) $u = 20$ m s^{-1}, $T = 2$ s
(d) $u = 20$ m s^{-1}, $T = 4$ s

34. A particle starts from rest and has an acceleration of 2 m s^{-2} for 10 s. After that, it travels for 30 seconds with constant speed and then undergoes a retardation of 4 m s^{-2} and comes back to rest. The total distance covered by the particle is

(a) 650 m (b) 750 m
(c) 700 m (d) 800 m

35. A body is projected vertically upwards at time $t = 0$ and is seen at a height H at time t_1 and t_2 seconds during its flight. The maximum height attained is [g is acceleration due to gravity]

(a) $\frac{g(t_2 - t_1)^2}{8}$ (b) $\frac{g(t_1 + t_2)^2}{4}$
(c) $\frac{g(t_1 + t_2)^2}{8}$ (d) $\frac{g(t_2 - t_1)^2}{4}$

36. A body travels for 15 seconds starting from rest with constant acceleration. If it travels distances S_1, S_2 and S_3 in the first five seconds, second five seconds and next five seconds respectively, then the relation between S_1, S_2 and S_3 is

(a) $S_1 = S_2 = S_3$ (b) $5S_1 = 3S_2 = S_3$
(c) $S_1 = \frac{1}{3}S_2 = \frac{1}{5}S_3$ (d) $S_1 = \frac{1}{5}S_2 = \frac{1}{3}S_3$

37. A body covers 200 cm in the first 2 seconds and 220 cm in the next 4 seconds. The velocity of the body at the end of the 7^{th} second is

(a) 10 cm s^{-1} (b) 20 cm s^{-1}
(c) 5 cm s^{-1} (d) 30 cm s^{-1}

38. A ball is dropped from a high rise platform at $t = 0$ starting from rest. After 6 seconds another ball is thrown downwards from the same platform with a speed v. The two balls meet at $t = 18$ s. What is the value of v? (Take $g = 10$ m s^{-2})

(a) 75 m s^{-1} (b) 55 m s^{-1}
(c) 40 m s^{-1} (d) 60 m s^{-1}

39. A man in a balloon rising vertically with an acceleration of 4.9 m s^{-2} releases a stone 2 seconds after the balloon is let go from the ground. The greatest height above the ground reached by the stone is (Take $g = 9.8$ m s^{-2})

(a) 14.7 m (b) 19.6 m
(c) 9.8 m (d) 24.5 m

40. Two cars are moving in the same direction with a speed of 30 km h^{-1}. They are separated from each other by 5 km. Third car moving in the opposite direction meats the two cars after an interval of 4 min. What is the speed of the third car?

(a) 30 km h^{-1} (b) 35 km h^{-1}
(c) 40 km h^{-1} (d) 45 km h^{-1}

41. From the top of tower, a stone is thrown up. It reaches the ground in t_1 s. A second stone thrown down with the same speed reaches the ground in t_2 s. A third stone released from rest reaches the ground in t_3 s. Then

(a) $t_3 = \frac{(t_1 + t_2)}{2}$ (b) $t_3 = \sqrt{t_1 t_2}$
(c) $\frac{1}{t_3} = \frac{1}{t_1} + \frac{1}{t_2}$ (d) $t_3^2 = t_2^2 - t_1^2$

42. A body travels a distance of 20 m in the 7^{th} second and 24 m in 9^{th} second. How much distance shall in travel in the 15^{th} second?

(a) 10 m (b) 16 m
(c) 24 m (d) 36 m

43. A body starting from rest moves with constant acceleration. The ratio of distance covered by the body during the 5^{th} second to that coverd in 5 seconds is

(a) $\frac{9}{25}$ (b) $\frac{3}{25}$
(c) $\frac{25}{9}$ (d) $\frac{1}{25}$

44. The velocity-time graph of a body moving in a straight line shown in the figure. The displacement and distance travelled by the body in 6 s are respectively

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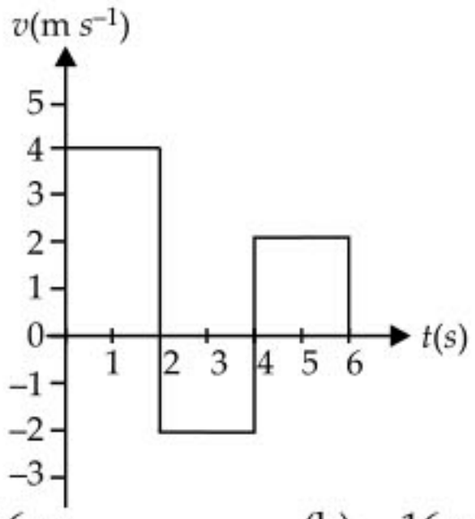
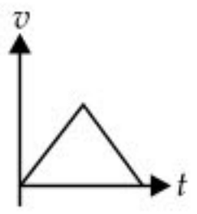
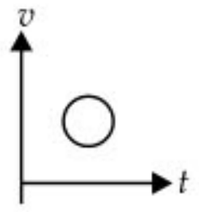
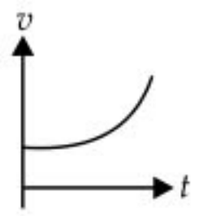


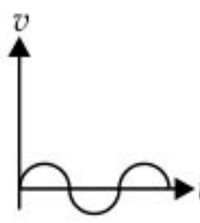
(a) 8 m, 16 m (b) 16 m, 8 m
(c) 16 m, 16 m (d) 8 m, 8 m

45. Which of the following curves does not represent motion in one dimension?

(a) 

(b) 

(c) 

(d) 

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DAY 02 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____

(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (c) : Let L be the length of escalator.

Speed of man w.r.t. escalator is $v_{mc} = \frac{L}{t_1}$

Speed of escalator is $v_c = \frac{L}{t_2}$

$\therefore$ Speed of man with respect to ground would be

$$v_m = v_{mc} + v_c = L\left(\frac{1}{t_1} + \frac{1}{t_2}\right)$$

$\therefore$ The desired time is $t = \frac{L}{v_m} = \frac{t_1 t_2}{t_1 + t_2}$

2. (c) : Displacement in 8 s = Algebraic sum of the area under velocity-time graph

$$= 2\times 2 + \frac{1}{2}\times 1\times 4 + 1\times 2 + \frac{1}{2}\times 1\times 6 - \frac{1}{2}\times 16 - 6\times 1 + 2\times 4$$

$= 4 + 2 + 2 + 3 - 3 - 6 + 8 = 10$ m,

3. (c) : The velocity of streamer while moving down-stream = 3 km h^{-1} + 2 km h^{-1} = 5 km h^{-1} and while moving upstream = 3 km h^{-1} – 2 km h^{-1} = 1 km h^{-1}.

$$\text{Total time taken} = \frac{2\,\text{km}}{5\,\text{km h}^{-1}} + \frac{2\,\text{km}}{1\,\text{km h}^{-1}} = 0.4\,\text{h} + 2\,\text{h} = 2.4\,\text{h}$$

4. (d) : When the lift is moving upwards with a uniform speed, its acceleration is zero.

$\therefore$ The reading of the machine is

$R = mg = (50\text{ kg})\,(10\text{ m s}^{-2}) = 500$ N

5. (d) : Time taken for the particle to reach the highest point is $\frac{t_1 + t_2}{2}$.

As $v = u - gt$

At highest point, $v = 0$

Therefore, initial velocity of the particle is

$$u = g\left(\frac{t_1 + t_2}{2}\right) \quad \ldots(i)$$

Therefore, height of point B from the ground is

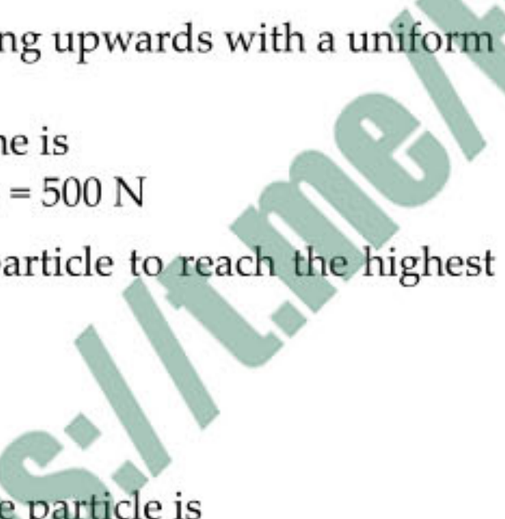
$$h = ut_1 - \frac{1}{2}gt_1^2 = g\left(\frac{t_1 + t_2}{2}\right)t_1 - \frac{1}{2}gt_1^2 \quad \text{(Using (i))}$$

$$\text{or} \quad h = g\left(\frac{t_1^2}{2} + \frac{t_1 t_2}{2}\right) - \frac{1}{2}gt_1^2 \quad \text{or} \quad h = \frac{1}{2}gt_1 t_2$$

6. (c) : Let the car accelerates for time t_1 and decelerates for time t_2. Then,

$t = t_1 + t_2$ …(i)

and corresponding velocity-time graph will be as shown in figure.



From the graph,

α = slope of line $OA = \frac{v_{max}}{t_1}$

$$\text{or} \quad t_1 = \frac{v_{max}}{\alpha} \quad \ldots(ii)$$

and β = slope of line $AB = \frac{v_{max}}{t_2}$

$$\text{or} \quad t_2 = \frac{v_{max}}{\beta} \quad \ldots(iii)$$

From Eqs. (i), (ii) and (iii), we get

$$t = \frac{v_{max}}{\alpha} + \frac{v_{max}}{\beta} \quad \text{or} \quad t = v_{max}\left(\frac{1}{\alpha} + \frac{1}{\beta}\right)$$

$$\text{or} \quad t = v_{max}\left(\frac{\alpha + \beta}{\alpha\beta}\right) \quad \text{or} \quad v_{max} = \frac{\alpha\beta t}{\alpha + \beta}$$

7. (b) : The greatest distance is, when velocities of both are equal.

or $ft = u$

$\therefore$ $t = \frac{u}{f}$

$$S_1 = ut = \frac{u^2}{f} \text{ and } S_2 = \frac{1}{2}ft^2 = \frac{u^2}{2f}$$

$\therefore$ $S_{max} = S_1 - S_2 = \frac{u^2}{2f}$

8. (b) : Let h be total height and t be the total time of flight. Then,

$$h = \frac{1}{2}\times 10\times t^2 = 5t^2 \quad \ldots(i)$$

and $h - 40 = \frac{1}{2}\times 10\times (t-2)^2 = 5(t^2 + 4 - 4t)$

Using (i), we get

$5t^2 - 40 = 5(t^2 + 4 - 4t)$ or $5t^2 - 40 = 5t^2 + 20 - 20t$

or $20t = 60$ or $t = 3$ s

$\therefore$ $h = 5(3)^2 = 45$ m

9. (a) : Here, $x = 4\sin 6t$, $y = 4(1 - \cos 6t)$

$$v_x = \frac{dx}{dt} = \frac{d}{dt}(4\sin 6t) = 24\cos 6t$$

$$v_y = \frac{dy}{dt} = \frac{d}{dt}4(1 - \cos 6t) = 24\sin 6t$$

$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{(24\cos 6t)^2 + (24\sin 6t)^2} = 24\text{ m s}^{-1}$$

i.e., speed of the particle is constant. Hence, the distance traversed by the particle in 4 s is

$s = vt = (24 \times 4)$ m = 96 m

10. (b) : Let the stone remains in air for n s.

$$D_n = u + \frac{g}{2}(2n - 1) = 0 + \frac{g}{2}(2n - 1) \quad (\ldots u = 0)$$

Distance travelled in first three seconds

$$S_3 = 0 \times 3 + \frac{1}{2} \times g \times 3^2 = \frac{9}{2}g \quad (\ldots u = 0)$$

As $D_n = S_3$ (Given)

$\therefore$ $\frac{g}{2}(2n - 1) = \frac{9}{2}g$ *or* $2n - 1 = 9$, $n = 5$ s

11. (b) : Let h be maximum height reached by the body. Taking motion of the body from half the maximum height upto the highest point, we have

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$u = 10\ \text{m s}^{-1}$, $a = -g = -10\ \text{m s}^{-2}$, $v = 0$, $S = \frac{h}{2}$

As $v^2 = u^2 + 2aS$

$\therefore \quad 0 = 10^2 + 2(-10) \times \frac{h}{2}$ or $h = 10\ \text{m}$

12. (d) : Given: $x = 40 + 12t - t^3$

$\therefore$ Velocity, $v = \frac{dx}{dt} = \frac{d}{dt}(40 + 12t - t^3) = 12 - 3t^2$

When particle comes to rest, $v = 0$

$\therefore \quad 0 = 12 - 3t^2$ or $t = 2\ \text{s}$

When $t = 0$, $x_0 = 40 + 12 \times 0 - 0^3 = 40\ \text{m}$

When $t = 2\ \text{s}$, $x_2 = 40 + 12 \times 2 - 2^3 = 56\ \text{m}$

$\therefore$ Distance travelled before coming to rest

$S = x_2 - x_0 = 56\ \text{m} - 40\ \text{m} = 16\ \text{m}$

13. (c) : When the drunkard walks 8 steps forward and 6 steps backward, the displacement in the first 14 steps $= 8\ \text{m} - 6\ \text{m} = 2\ \text{m}$

Time taken for first 14 steps = 14 s

Time taken by drunkard to cover first 10 m of journey

$= \frac{14}{2} \times 10 = 70\ \text{s}$

If the drunkard takes 8 steps more, he will fall into the pit, so the time taken by the last 8 steps = 8 s

Total time taken = 70 s + 8 s = 78 s

14. (a) : Refer figure, at time t,

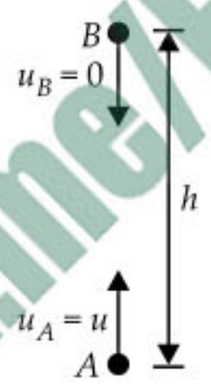
Velocity of A, $v_A = u - gt$ (upwards)

Velocity of B, $v_B = gt$ (downwards)

$= -gt$ (upwards)

Relative velocity of A w.r.t. B is

$v_{AB} = v_A - v_B = (u - gt) - (-gt) = u$



15. (c) : For first one-third of distance

Distance covered $= \frac{x}{3}$ km

Speed = 10 km h^{-1}.

The time taken for the journey, $t_1 = \frac{x/3}{10}\ \text{h} = \frac{x}{30}\ \text{h}$

For the next one-third of distance :

Distance covered $= \frac{x}{3}$ km.

Speed = 20 km h^{-1}

The time taken for travel is $t_2 = \frac{x/3}{20}\ \text{h} = \frac{x}{60}\ \text{h}$

For the last one-third of distance :

Distance covered $= \frac{x}{3}$ km.

Speed is 60 km h^{-1}

The time taken for travel is $t_3 = \frac{x/3}{60}\ \text{h} = \frac{x}{180}\ \text{h}$

$\therefore \quad$ Average Speed $= \frac{\text{total distance}}{\text{total time}} = \frac{x}{\frac{x}{30} + \frac{x}{60} + \frac{x}{180}}$

$= \frac{180x}{10x} = 18\ \text{km h}^{-1}$

16. (b) : Distance travelled in 3rd second

$S_3 = 10 + \frac{10}{2}(2 \times 3 - 1) = 35\ \text{m}$

Distance travelled in 2nd second,

$S_2 = 10 + \frac{10}{2}(2 \times 2 - 1) = 25\ \text{m} \quad \Rightarrow \quad \frac{S_3}{S_2} = \frac{7}{5}$

17. (d) : Given : $x^2 = 2t^2 + 6t + 1$ ...(i)

Differentiating with respect to t, we get

$2x\frac{dx}{dt} = 4t + 6$

$\therefore \quad xv = 2t + 3 \quad \left(\because \frac{dx}{dt} = v\right)$ ...(ii)

Again differentiating both sides w.r. to t we get,

$x\frac{dv}{dt} + \frac{vdx}{dt} = 2$

$xa + v^2 = 2 \quad \left(\because \frac{dv}{dt} = a\right)$

$a = \frac{2 - v^2}{x}$

$a = \frac{1}{x}\left[2 - \left[\frac{(2t+3)^2}{x}\right]\right]$ Using (ii)

$= \frac{1}{x}\left[\frac{2x^2 - (2t+3)^2}{x^2}\right]$

$= \frac{1}{x}\left[\frac{2(2t^2 + 6t + 1) - (4t^2 + 9 + 12t)}{x^2}\right]$ Using (i)

$= \frac{1}{x}\left[\frac{4t^2 + 12t + 2 - 4t^2 - 9 - 12t}{x^2}\right]$ or $a \propto \frac{-1}{x^3}$

18. (b) : Given, $x = 9t^2 - t^3$ ...(i)

$v = \frac{dx}{dt} = 18t - 3t^2$

and $a = \frac{dv}{dt} = 18 - 6t$ ...(iii)

Now, when speed of particle is maximum, its acceleration is zero, *i.e.*, $a = 0$

$\therefore \quad 18 - 6t = 0$ or $t = 3\ \text{s}$

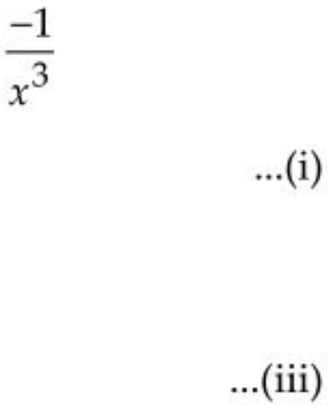
Putting in Eq. (i), we obtain position of particle at that time

$x = 9(3)^2 - (3)^3 = 54\ \text{m}$

19. (c) : Parachute bails out at height H from ground. Velocity at A

$u = \sqrt{2gh} = \sqrt{980}\ \text{m s}^{-1}$

when parachute opens, it decelerates at 2 m s^{-2} and he reaches the ground with a speed, $v = 3\ \text{m s}^{-1}$



$\therefore \quad H - h = \frac{v^2 - u^2}{2 \times 2} = 242.75$

$\therefore \quad H = 224.75 + h = 242.75 + 50 = 292.75\ \text{m} = 293\ \text{m}$

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20. (a) : Here, total distance travelled = 8.4 + 2 = 10.4 km

$$\text{Total time taken} = \frac{8.4}{70} + \frac{1}{2} = 0.62 \text{ h}$$

$$\text{Average velocity} = \frac{\text{Total distance travelled}}{\text{Total time taken}}$$

$$= \frac{10.4}{0.62} = 16.8 \text{ km h}^{-1}$$

21. (c) : The speed of an object falling freely under gravity, depends only upon its height from which it is allowed to fall and not upon its mass. Since the paths are frictionless and all the objects are falling through the same vertical height, therefore their speeds on reaching the ground must be same or ratio of their speeds = 1 : 1 : 1.

22. (a) : $u = 0$, $a = 2 \text{ m s}^{-2}$, $t = 10 \text{ s}$

$$\therefore \quad s_1 = ut + \frac{1}{2}at^2 = 0 + \frac{1}{2} \times 2 \times 100 = 100 \text{ m}$$

Velocity after 10 s,

$$v = u + at = 0 + 2 \times 10 = 20 \text{ m s}^{-1}$$

$$\therefore \quad s_2 = v \times 30 = 20 \times 30 = 600 \text{ m}$$

Final velocity = 0, $a = -4 \text{ m s}^{-2}$

$$\therefore \quad 0 = v^2 + 2as_3$$

$$0 = (20)^2 - 2 \times 4 \times s_3$$

$$\therefore \quad s_3 = \frac{400}{8} = 50 \text{ m}$$

$$\therefore \quad s = s_1 + s_2 + s_3 = 100 + 600 + 50 = 750 \text{ m}$$

23. (c) : Let the speed of man be v and time taken by him to just get into the train be t. The distance traveled by train in time t is given by

$$x_1 = 0 \times t + \frac{1}{2} \times 2 \times t^2 = t^2$$

To get into the train, the distance traveled by the man is

$$x = x_1 + 9 = t^2 + 9 \qquad \text{...(i)}$$

As the man covers the distance x with uniform speed in time t, we have

$$x = vt \qquad \text{...(ii)}$$

Substitutiong Eq. (ii) in (i), we get

$$vt = t^2 + 9 \Rightarrow t^2 - vt + 9 = 0 \Rightarrow t = \frac{v \pm \sqrt{v^2 - 36}}{2}$$

For real value of t, the discriminant of the above quadratic equation should be greater than or equal to zero.

$$\sqrt{v^2 - 36} \geq 0 \Rightarrow v^2 \geq 36 \Rightarrow v \geq 6.$$

Therefore, the speed of the man to get into the train is 6 m s^{-1}.

24. (c) : Acceleration is given by

$$a = \frac{dv}{dt} = \frac{dv}{dx}\left(\frac{dx}{dt}\right) = v\left(\frac{dv}{dx}\right)$$

But equation of velocity is in the form $v = -mx + C$, where $-m$ is the slope, which is negative.

$$a = (-mx + C)(-m) = m^2x - mC.$$

The equation of acceleration has a positive slope and a negative y-intercept at mC. Graph shown in figure (c) satisfies these conditions.

Hence, the correct option is (c).

25. (a)

26. (c) : Let time taken by ball to reach maximum height be T.

Also $v = u - gT$

At maximum height, final speed is zero i.e, $v = 0$

So, $u = gT$ (Using (i))

In 2 s, $u = 2 \times 9.8 = 19.6 \text{ m s}^{-1}$

Hence, the speed should be more than 19.6 m s^{-1}.

27. (b)

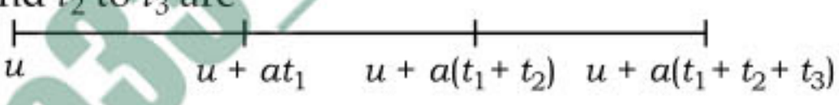
28. (c) : $v_1 = \sqrt{2gh} = \sqrt{2 \times 10 \times 10} = \sqrt{200}$

$$v_2 = -\sqrt{2gh} = -\sqrt{2 \times 10 \times 2.5} = -\sqrt{50}$$

So $\Delta v = v_1 - v_2 = \sqrt{200} + \sqrt{50} = 3\sqrt{50} = 21$

$$\therefore \quad \text{Acceleration} = \frac{\Delta v}{\Delta t} = \frac{21}{0.01} = 2100 \text{ m s}^{-2}$$

29. (d) : Average velocities in the intervals from 0 to t_1, t_1 to t_2 and t_2 to t_3 are



$$v_1 = \frac{u + u + at_1}{2} = u + \frac{a}{2}t_1$$

$$v_2 = \frac{u + at_1 + u + a(t_1 + t_2)}{2} = u + at_1 + \frac{a}{2}t_2$$

$$v_3 = \frac{u + a(t_1 + t_2) + u + a(t_1 + t_2 + t_3)}{2} = u + at_1 + at_2 + \frac{a}{2}t_3$$

$$v_2 - v_1 = \frac{a}{2}(t_1 + t_2)$$

$$v_3 - v_2 = \frac{a}{2}(t_2 + t_3)$$

$$\therefore \quad \frac{v_2 - v_1}{v_3 - v_2} = \frac{(t_1 + t_2)}{(t_2 + t_3)} \quad \text{or} \quad \frac{v_1 - v_2}{v_2 - v_3} = \frac{(t_1 + t_2)}{(t_2 + t_3)}$$

30. (d) : For $t \leq 2$ s, $v = 2t - 4$

$$\therefore \quad S_1 = ut + \frac{1}{2}at^2 = (-4)(2) + \frac{1}{2}(2)(2)^2$$

$$= -8 + 4 = -4 \text{ m}$$

For $t > 2$ s, $v = 4 - 2t$

$$\therefore \quad S_2 = ut + \frac{1}{2}at^2 = 0 + \frac{1}{2}(-2)(2)^2 = -4 \text{ m}$$

$$\therefore \quad \text{Distance, } S = |S_1| + |S_2| = 8 \text{ m}$$

31. (b) : For particle 1 moving with constant velocity,

$$S_1 = 50t \qquad \text{...(i)}$$

For particle 2 moving with constant acceleration,

$$S_2 = \frac{1}{2}at^2 = \frac{1}{2} \times 10t^2 = 5t^2 \qquad \text{...(ii)}$$

As per question; $S_2 - S_1 = 125$, we get

From equations (i) & (ii)

$$5t^2 - 50t = 125 \text{ or } t^2 - 10t - 25 = 0.$$

On solving , we get

$$t = (5 \pm 5\sqrt{2}) \text{ s}$$

$$\therefore \quad t = (5 + 5\sqrt{2}) \text{ s} \text{ or } t = 5(1 + \sqrt{2}) \text{ s}$$

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32. (b) : Let S be the total distance travelled by the body. Let t_1 be the time taken by the body to travel first half of the distance. Then

$$t_1 = \frac{\left(\frac{S}{2}\right)}{2} = \frac{S}{4}$$

Let t_2 be the time taken by body for each time interval for the remaining half journey. Therefore,

$$\therefore \quad \left(\frac{S}{2}\right) = 3t_2 + 5t_2 = 8t_2 \text{ or } t_2 = \frac{S}{16}$$

$$\text{Average speed, } v_{av} = \frac{S}{t_1 + 2t_2} = \frac{S}{\frac{S}{4} + 2\left(\frac{S}{16}\right)} = \frac{8}{3} \text{ m s}^{-1}$$

33. (d) : Taking vertically upward motion of ball, we have

$$v^2 = u^2 + 2gs$$

or $0 = u^2 + 2 \times (-10) \times 20$ or $u = 20 \text{ m s}^{-1}$

Taking vertical motion of ball for whole flight,

$$S = ut + \frac{1}{2}gt^2$$

$$0 = 20 \times t + \frac{1}{2} \times (-10) \times t^2$$

$$5t^2 - 20\,t = 0 \Rightarrow t = 4 \text{ s.}$$

34. (b) : Distance covered in first 10 seconds

$$= \frac{1}{2}at^2 = \frac{1}{2} \times 2 \times (10)^2 = 100 \text{ m}$$

Velocity after 10 seconds, $v = u + at = 0 + 2 \times 10 = 20 \text{ m s}^{-1}$

Distance covered in 30 seconds $= 20 \times 30 = 600$ m

During retardation, distance travelled

$$= \frac{v^2 - u^2}{2a} = \frac{0 - (20)^2}{2(-4)} = 50 \text{ m}$$

Total distance $= 100 + 600 + 50 = 750$ m

35. (c) : When the body is projected vertically upwards with velocity u it occupies the same position while going up and coming down after time of t_1 and t_2.

$$\therefore \quad H = ut - \frac{1}{2}gt^2$$

$$gt^2 - 2ut + 2H = 0$$

It is a quadratic equation in t, and t_1 and t_2 are the two roots of this equation.

$$\therefore \quad \text{Sum of roots} = t_1 + t_2 = -\left(\frac{-2u}{g}\right) = \frac{2u}{g}$$

$$\text{or } u = \frac{g(t_1 + t_2)}{2}$$

The maximum height attained is

$$H_{max} = \frac{u^2}{2g} = \frac{1}{2g}\left[\frac{g(t_1 + t_2)}{2}\right]^2 = \frac{g(t_1 + t_2)^2}{8}$$

36. (c) : Let a be uniform acceleration of the body.

$$\text{As } S = ut + \frac{1}{2}at^2 = \frac{1}{2}at^2 \qquad (\because u = 0)$$

$$\text{Then, } S_1 = \frac{1}{2}a(5)^2 \qquad \text{...(i)}$$

$$S_1 + S_2 = \frac{1}{2}a(10)^2 \qquad \text{...(ii)}$$

$$S_1 + S_2 + S_3 = \frac{1}{2}a(15)^2 \qquad \text{...(iii)}$$

Subtract (i) from (ii), we get

$$(S_1 + S_2) - S_1 = \frac{1}{2}a(10)^2 - \frac{1}{2}a(5)^2$$

$$S_2 = \frac{75}{2}a = 3S_1 \qquad \text{(Using (i))}$$

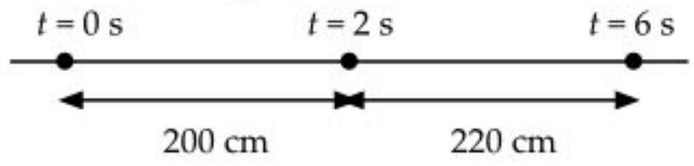
Subtract (ii) from (iii), we get

$$(S_1 + S_2 + S_3) - (S_1 + S_2) = \frac{1}{2}a(15)^2 - \frac{1}{2}a(10)^2$$

$$S_3 = \frac{125}{2}a = 5S_1 \qquad \text{(Using (i))}$$

Thus, $S_1 = \frac{1}{3}S_2 = \frac{1}{5}S_3$

37. (a) : Let u and a be the initial velocity and uniform acceleration of the body.



Using $S = ut + \frac{1}{2}at^2$

$$\therefore \quad 200 = u(2) + \frac{1}{2}a(2)^2$$

$$100 = u + a \qquad \text{...(i)}$$

$$\text{Also } 420 = 6u + \frac{1}{2}a(6)^2$$

$$70 = u + 3a \qquad \text{...(ii)}$$

Solving equations (i) and (ii), we get

$$u = 115 \text{ cm s}^{-1}, \; a = -15 \text{ cm s}^{-2}$$

Using $v = u + at$

$$\therefore \quad v = 115 + (-15)7 = 10 \text{ cm s}^{-1}$$

38. (a) : Let the two balls meet after t s at distance x from the platform.

For the first ball $u = 0$, $t = 18$ s, $g = 10 \text{ m s}^{-2}$

Using $h = ut + \frac{1}{2}gt^2$

$$\therefore \quad x = \frac{1}{2} \times 10 \times 18^2 \qquad \text{...(i)}$$

For the second ball $u = v$, $t = 12$ s, $g = 10 \text{ m s}^{-2}$

Using $h = ut + \frac{1}{2}gt^2$

$$\therefore \quad x = v \times 12 + \frac{1}{2} \times 10 \times 12^2 \qquad \text{...(ii)}$$

From equations (i) and (ii), we get

$$\frac{1}{2} \times 10 \times 18^2 = 12v + \frac{1}{2} \times 10 \times (12)^2$$

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$$12v = \frac{1}{2}\times 10\times[(18)^2-(12)^2] = \frac{1}{2}\times 10\times[(18+12)(18-12)]$$

or $\quad v = \dfrac{1\times 10\times 30\times 6}{2\times 12} = 75 \text{ m s}^{-1}$

39. (a) : Here, $a = 4.9 \text{ m s}^{-2}$, $t = 2 \text{ s}$, $u = 0$

$$s = ut + \frac{1}{2}at^2$$

$$s = 0 + \frac{1}{2}\times 4.9\times(2)^2 = 9.8 \text{ m}$$

This is the height from where stone is dropped.
Upward velocity of stone when released,
$v = u + at = 0 + 4.9 \times 2 = 9.8 \text{ m s}^{-1}$
The stone will move up till its velocity become zero.
From, $v^2 - u^2 = 2as$
$0 - (9.8)^2 = 2(-9.8)s' \quad \therefore \quad s' = 4.9 \text{ m}$
Maximum height above the ground
$= s + s' = 9.8 \text{ m} + 4.9 \text{ m} = 14.7$

40. (d) : Let speed of the third car be v km h^{-1}.
Then, relative speed of third car with respect to two cars
$= (v + 30)$ km h^{-1}
Two cars are separated by 5 km and third car crosses them in 4 min.

$$\therefore \quad v + 30 = \frac{5\times 60}{4} = 75 \Rightarrow v = 75 - 30 = 45 \text{ km h}^{-1}$$

41. (b) : When stone is thrown vertically upwards from the top of tower of height h, then

$$h = -ut_1 + \frac{1}{2}gt_1^2 \qquad ...(i)$$

When stone is thrown vertically downwards from the top of tower, then

$$h = -ut_2 + \frac{1}{2}gt_2^2 \qquad ...(ii)$$

When stone is released from the top of tower, then

$$h = \frac{1}{2}gt_3^2 \qquad ...(iii)$$

From equation (i), we get

$$\frac{h}{t_1} = -u + \frac{1}{2}gt_1 \qquad ...(iv)$$

From equation (ii), we get

$$\frac{h}{t_2} = u + \frac{1}{2}gt_2 \qquad ...(v)$$

Adding equations (iv) and (v). we get

$$h\left(\frac{1}{t_1}+\frac{1}{t_2}\right) = \frac{1}{2}g(t_1+t_2) \text{ or } h = \frac{1}{2}g\,t_1t_2$$

Putting the value in equation (iii), we get

$$t_3 = \sqrt{t_1t_2}$$

42. (d) : Here, $D_7 = 20$ m, $D_9 = 24$ m, $D_{15} = ?$
Let u and a be the initial velocity and uniform acceleration of the body.

$$D_n = u + \frac{a}{2}(2n-1) \quad \therefore \quad D_7 = u + \frac{a}{2}(2\times 7 - 1)$$

or $\quad 20 = u + \dfrac{13a}{2} \qquad ...(i)$

and $\quad D_9 = u + \dfrac{a}{2}(2\times 9 - 1)$ or $\quad 24 = u + \dfrac{17}{2}a \qquad ...(ii)$

Substracting equation (i) from equation (ii), we get
$4 = 2a$ or $a = 2 \text{ m s}^{-2}$
Putting this value in equation (i), we get

$$20 = u + \frac{13}{2}\times 2 = u + 13$$

or $\quad u = 20 - 13 = 7 \text{ m s}^{-1}$

$$\therefore \quad D_{15} = u + \frac{a}{2}(2\times 15 - 1) = 7 + \frac{2}{2}\times 29 = 36 \text{ m}$$

43. (a) : Distance covered in 5th second is

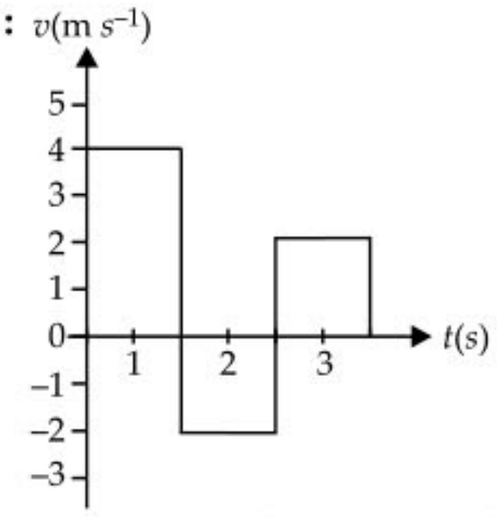
$$D_5 = 0 + \frac{a}{2}(2\times 5 - 1) = \frac{9a}{2}$$

Distance covered in 5 seconds is

$$S_5 = 0 + \frac{1}{2}\times a\times 5^2 = \frac{25a}{2}$$

$$\therefore \quad \frac{D_5}{S_5} = \frac{9}{25}$$

44. (a) :



Displacement is equal to area under velocity-time graph with proper sign
$\therefore$ Displacement $= 4 \times 2 - 2 \times 2 + 2 \times 2 = 8$ m
Distance is equal to total are under the speed-time graph.
$\therefore$ Distance $= 4 \times 2 + 2 \times 2 + 2 \times 2 = 16$ m

45. (b) : In one dimensional motion, the body can have at a time one value of velocity but not two values of velocities.

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Motion in a Plane

Vectors

The physical quantities which have both magnitude as well as direction are known as vector quantities or vectors. e.g. force, velocity etc.

Representation of a vector : A vector is represented by a straight line with arrow head on it. The length of the line represents the magnitude of a vector and arrow head tells the direction of vector. In writing, a vector is represent by a single letter with a arrow head on it. e.g. the force is a vector quantity, it is represented by $\vec{F}$.

Vectors are of two types

(i) Polar vectors : A polar vector involves a displacement or virtual displacement. e.g. velocity, force, etc.

(ii) Axial vectors or Pseudo vectors : A pseudo vector or axial vector involves the orientation of an axis in space. e.g. angular velocity, torque, angular momentum, etc.

Equal vectors : Two vectors are said to be equal if they have same magnitude and direction regardless of their initial positions.

Negative vector : It is a vector having same magnitude but direction opposite to that of a given vector.

Null vector : It is a vector whose magnitude is zero, but its direction is not defined.

Properties of a null vector

(i) $\vec{A}+\vec{O}=\vec{A}$

(ii) $\lambda\vec{O}=\vec{O}$ where λ is a scalar.

(iii) $O\vec{A}=\vec{O}$

Unit vector : A vector having magnitude equal to unity. To find the unit vector in the direction $\vec{A}$, we divide the given vector by its magnitude.

e.g. $\hat{A}=\dfrac{\vec{A}}{|\vec{A}|}$

Co-initial vectors : The vectors are said to be co-initial, if their initial point is common.

Collinear vectors : These are those vectors which are having equal or unequal magnitudes and are acting along the parallel straight lines.

Coplanar vectors : These are those vectors which are acting in the same plane.

Laws of vector algebra : If $\vec{A}$, $\vec{B}$ and $\vec{C}$ are vectors, and m and n are scalars, then

(i) Commutative law for addition

$\vec{A}+\vec{B}=\vec{B}+\vec{A}$

(ii) Associative law for addition

$\vec{A}+(\vec{B}+\vec{C})=(\vec{A}+\vec{B})+\vec{C}$

(iii) Associative law for multiplication

$m(n\vec{A})=(mn)\vec{A}=n(m\vec{A})$

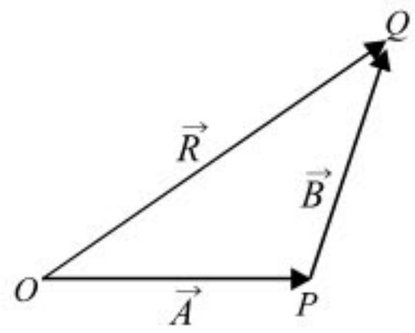
(iv) Distributive law

$(m+n)\vec{A}=m\vec{A}+n\vec{A}$

- **Triangle law of vector addition:** It states that if two vectors can be represented both in magnitude and direction by the two sides of a triangle taken in the same order, then the resultant is represented completely (both in magnitude and direction) by the third side of the triangle taken in the opposite order.

$\vec{R}$ is the resultant of $\vec{A}$ and $\vec{B}$ as shown in figure, then

$\vec{R}=\vec{A}+\vec{B}$



- **Parallelogram law of vector addition :** It states that if two vectors acting simultaneously at a point can be represented both in magnitude and direction by the two adjacent sides of a parallelogram, then the resultant is represented completely (both in magnitude and direction) by the diagonal of the parallelogram passing through that point.

$\vec{R}$ is the resultant of $\vec{A}$ and $\vec{B}$ as shown in figure, then,

$R=\sqrt{A^2+B^2+2AB\cos\theta}$

$\tan\beta=\dfrac{B\sin\theta}{A+B\cos\theta}$

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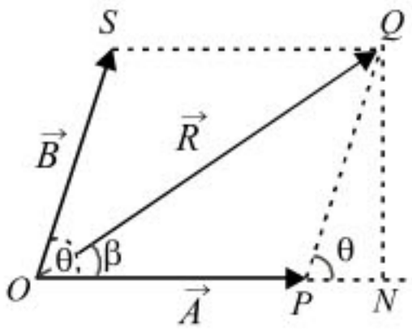


☛ **Polygon law of vector addition :** It states that if a number of vectors can be represented both in magnitude and direction by the sides of a polygon taken in the same order, then their resultant is represented (both in magnitude and direction) by the closing side of the polygon taken in the opposite order.

Rectangular component of a vector in a plane : When a vector is splitted into two component vectors at right angles to each other, the component vectors are called rectangular components of a vector. If $\vec{A}$ makes an angle θ with x-axis, and A_x and A_y be the rectangular components of $\vec{A}$ along x-axis and y-axis respectively, then

$$\vec{A} = A_x\hat{i} + A_y\hat{j}$$

Here $A_x = A\cos\theta$ and $A_y = A\sin\theta$

$\therefore \quad A_x^2 + A_y^2 = A^2(\cos^2\theta + \sin^2\theta)$

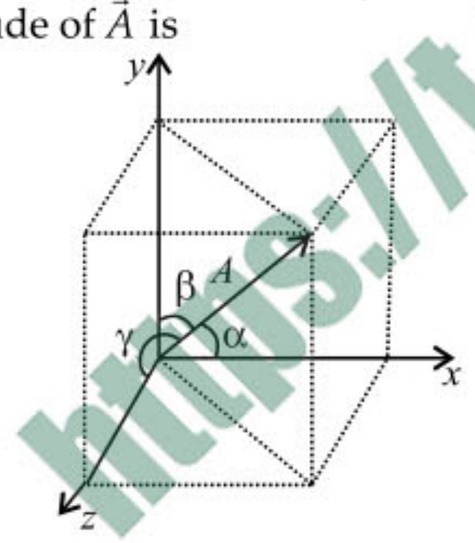
or $\quad A = (A_x^2 + A_y^2)^{1/2}$ and $\tan\theta = A_y/A_x$.

Resolution of a vector in a space : Let α, β, and γ are the angles between $\vec{A}$ and the x, y and z-axis, respectively as shown in the figure, then

$A_x = A\cos\alpha$, $A_y = A\cos\beta$, $A_z = A\cos\gamma$

In general, we have $\vec{A} = A_x\hat{i} + A_y\hat{j} + A_z\hat{k}$

The magnitude of $\vec{A}$ is



$$A = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

Dot or Scalar Product

The dot or scalar product of two vectors $\vec{A}$ and $\vec{B}$ denoted by $\vec{A}\cdot\vec{B}$ (read $\vec{A}$ dot $\vec{B}$) is defined as the product of the magnitudes of $\vec{A}$ and $\vec{B}$ and the cosine of the angle between them. In symbols, $\vec{A}\cdot\vec{B} = AB\cos\theta, \quad 0 \le \theta \le \pi$

Note $\vec{A}\cdot\vec{B}$ is a scalar and not a vector.

☛ **Properties of dot product**

(i) $\vec{A}\cdot\vec{B} = \vec{B}\cdot\vec{A}$

(ii) $\vec{A}\cdot(\vec{B}+\vec{C}) = \vec{A}\cdot\vec{B} + \vec{A}\cdot\vec{C}$

(iii) $m(\vec{A}\cdot\vec{B}) = (m\vec{A})\cdot\vec{B} = \vec{A}\cdot(m\vec{B}) = (\vec{A}\cdot\vec{B})m$,
where m is a scalar.

(iv) $\hat{i}\cdot\hat{i} = \hat{j}\cdot\hat{j} = \hat{k}\cdot\hat{k} = 1$, $\hat{i}\cdot\hat{j} = \hat{j}\cdot\hat{k} = \hat{k}\cdot\hat{i} = 0$

(v) If $\vec{A} = A_1\hat{i} + A_2\hat{j} + A_3\hat{k}$ and $\vec{B} = B_1\hat{i} + B_2\hat{j} + B_3\hat{k}$, then

$$\vec{A}\cdot\vec{B} = A_1B_1 + A_2B_2 + A_3B_3$$

$$\vec{A}\cdot\vec{A} = A^2 = A_1^2 + A_2^2 + A_3^2$$

$$\vec{B}\cdot\vec{B} = B^2 = B_1^2 + B_2^2 + B_3^2$$

(vi) If $\vec{A}\cdot\vec{B} = 0$ and $\vec{A}$ and $\vec{B}$ are not null vectors, then $\vec{A}$ and $\vec{B}$ are perpendicular.

Cross or Vector Product

The cross or vector product of $\vec{A}$ and $\vec{B}$ is a vector $\vec{C} = \vec{A}\times\vec{B}$ (read $\vec{A}$ cross $\vec{B}$). The magnitude of $\vec{A}\times\vec{B}$ is defined as the product of the magnitudes of $\vec{A}$ and $\vec{B}$ and the sine of the angle between them. The direction of the vector $\vec{C} = \vec{A}\times\vec{B}$ is perpendicular to the plane $\vec{A}$ and $\vec{B}$ and such that $\vec{A}$, $\vec{B}$ and $\vec{C}$ form a right handed system. In symbols,

$\vec{A}\times\vec{B} = AB\sin\theta\hat{n}$, $0 \le \theta \le \pi$

where $\hat{n}$ is a unit vector indicating the direction of $\vec{A}\times\vec{B}$.

☛ **Properties of vector product**

(i) $\vec{A}\times\vec{B} = -\vec{B}\times\vec{A}$

(ii) $\vec{A}\times(\vec{B}+\vec{C}) = \vec{A}\times\vec{B} + \vec{A}\times\vec{C}$

(iii) $m(\vec{A}\times\vec{B}) = (m\vec{A})\times\vec{B} = \vec{A}\times(m\vec{B}) = (\vec{A}\times\vec{B})m$
where m is a scalar.

(iv) $\hat{i}\times\hat{i} = \hat{j}\times\hat{j} = \hat{k}\times\hat{k} = 0$, $\hat{i}\times\hat{j} = \hat{k}, \hat{j}\times\hat{k} = \hat{i}, \hat{k}\times\hat{i} = \hat{j}$

(v) If $\vec{A} = A_1\hat{i} + A_2\hat{j} + A_3\hat{k}$
and $\vec{B} = B_1\hat{i} + B_2\hat{j} + B_3\hat{k}$, then

$$\vec{A}\times\vec{B} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ A_1 & A_2 & A_3 \\ B_1 & B_2 & B_3 \end{vmatrix}$$

(vi) $\vec{A}\times\vec{B}$ = the area of a parallelogram with sides $\vec{A}$ and $\vec{B}$.

(vii) If $\vec{A}\times\vec{B} = 0$ and $\vec{A}$ and $\vec{B}$ are not null vectors, then $\vec{A}$ and $\vec{B}$ are parallel.

Relative Motion

The term relative is frequently used for comparison of displacement, velocity and acceleration of two bodies.

The relative velocity of an object Q with respect to object P when both are in motion, is the time rate of change of position of object Q with respect to that of object P.

Relative velocity of a body A with respect to body B, when they are moving in the same direction is given by

$$\vec{v}_{AB} = \vec{v}_A - \vec{v}_B$$

Relative velocity of a body A with respect to body B when they are moving in the opposite direction is given by

$$\vec{v}_{AB} = \vec{v}_A + \vec{v}_B$$

The magnitude of a relative velocity of a body A with respect to body B, when they are inclined at an angle θ is given by $v_{AB} = \sqrt{(v_A)^2 + (v_B)^2 + 2(v_A)(v_B)\cos(180^\circ - \theta)}$

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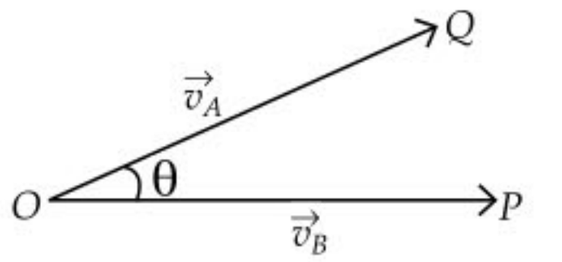
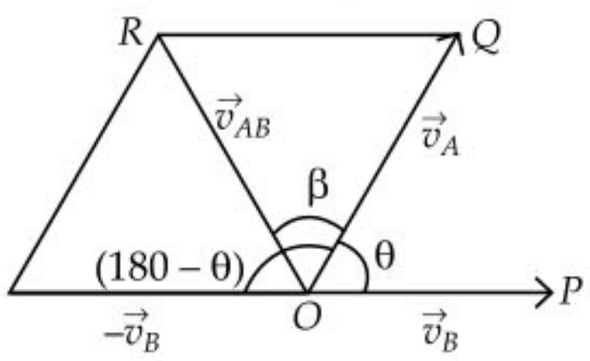
$$= \sqrt{v_A^2 + v_B^2 - 2v_A v_B \cos\theta}$$

$$\tan\beta = \frac{(v_B)\sin(180° - \theta)}{(v_A) + (v_B)\cos(180° - \theta)} = \frac{v_B \sin\theta}{v_A - v_B \cos\theta}$$

where $\vec{v}_A$ and $\vec{v}_B$ are velocities of two bodies A and B, β is an angle which $\vec{v}_{AB}$ makes with the direction of $\vec{v}_A$.





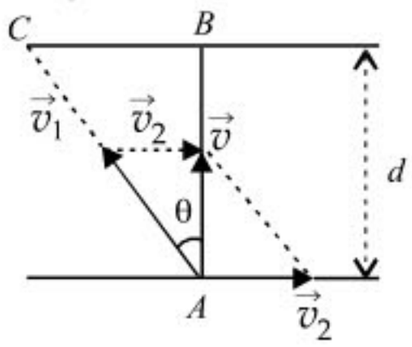
Rain Man Problem

If rain is falling vertically with a velocity $\vec{v}_r$ and a man is moving horizontally with speed $\vec{v}_m$, the man can protect himself from the rain if he holds his umbrella in the direction of relative velocity of rain w.r.t. man. If θ is the angle which the direction of relative velocity of rain w.r.t. man makes with the vertical, then $\tan\theta = v_m/v_r$.

Boat-River Problem

Let $\vec{v}_1$ = velocity of boat in still water, $\vec{v}_2$ = velocity of flow of water in river, d = width of river.

- **To cross the river in the shortest path :** Here it is required that the boat starting from A must reach the opposite point B along the shortest path AB. For the shortest path, the boat should be rowed upstream making an angle θ with AB such that AB gives the direction of resultant velocity.

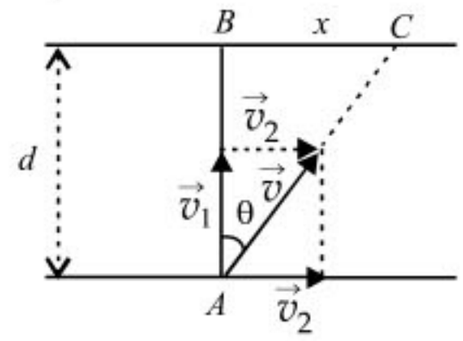


So, $\sin\theta = \frac{v_2}{v_1}$ and $v^2 = v_1^2 - v_2^2$

Also $t = \frac{d}{v} = \frac{d}{\sqrt{v_1^2 - v_2^2}}$

- **To cross the river in the shortest time :** For the boat to cross the river in shortest time, the boat should be directed along AB. Let v be the resultant velocity making an angle θ with AB.

Then $\tan\theta = \frac{v_2}{v_1}$ and $v^2 = v_1^2 + v_2^2$



Time of crossing, $t = d/v_1$

Now the boat reaches the point C rather than reaching point B. If $BC = x$, then

$$\tan\theta = \frac{v_2}{v_1} = \frac{x}{d} \quad \text{or} \quad x = d \times \left(\frac{v_2}{v_1}\right)$$

- If a man travels downstream in a river, then the time taken by the man to cover a distance d is $t_1 = \frac{d}{v_1 + v_2}$.

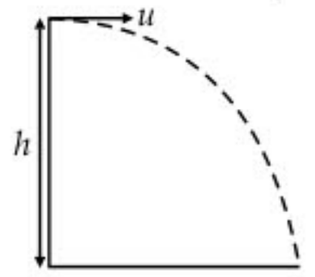
  If a man swims upstream in a river, then the time taken by him to cover a distance d is $t_2 = \frac{d}{v_1 - v_2}$. So $\frac{t_1}{t_2} = \frac{v_1 - v_2}{v_1 + v_2}$.

Projectile

Any body given an initial velocity moves freely in space under the influence of gravity is called a projectile.
A javelin thrown by an athlete and a ball kicked from the ground level are the examples of projectile motion.
The path followed by a projectile is called its trajectory.
Trajectory of a projectile is a parabola.

Projectile Motion

If a body is thrown with some initial velocity with the horizontal direction, and then allowed to move in two dimensions under the action of gravity alone without being propelled by any machine, then the motion of body is known as projectile motion.



To study the motion of a projectile, we have to make following assumptions.

- There is no frictional resistance of air.
- The acceleration due to gravity is constant in magnitude and direction at all points of the motion of projectile.

If a projectile projected horizontally from a height h with velocity u,

- Time taken by the projectile to reach the ground, $T = \sqrt{\frac{2h}{g}}$
- Horizontal range, $R = u\sqrt{\frac{2h}{g}}$
- Equation of trajectory is $y = \frac{g}{2u^2}x^2$

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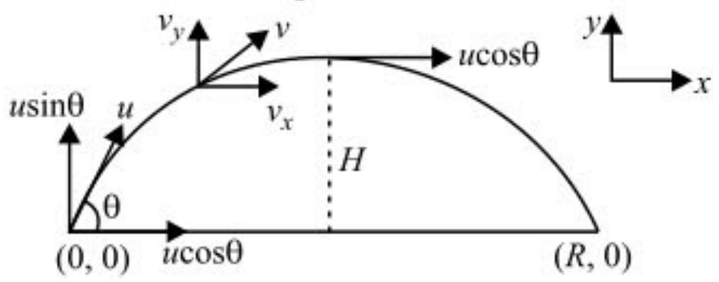
- Resultant velocity of the projectile at any time, t is $v = \sqrt{u^2 + g^2t^2}$
- Angle made by horizontal velocity with the horizontal is $\tan\beta = \frac{gt}{u}$
- Velocity of the projectile on striking the ground $= \sqrt{u^2 + 2gh}$

Projectile Fired at an Angle with the Horizontal



Suppose a projectile is fired with velocity u at an angle θ with the horizontal. Let it reach the point (x, y) after time t. Then

Components of initial velocity,

$u_x = u\cos\theta,\ u_y = u\sin\theta$

Components of acceleration at any instant,

$a_x = 0,\ a_y = -g$

Position after time t,

$x = (u\cos\theta)\,t,\ \ y = (u\sin\theta)\ t - \frac{1}{2}gt^2$

Equation of trajectory,

$$y = x\tan\theta - \frac{g}{2u^2\cos^2\theta}x^2$$

Maximum height, $H = \frac{u_y^2}{2g} = \frac{u^2\sin^2\theta}{2g}$

Time of flight, $T = \frac{2u_y}{g} = \frac{2u\sin\theta}{g}$

Horizontal range, $R = \frac{2u_x u_y}{g} = \frac{u^2\sin 2\theta}{g}$

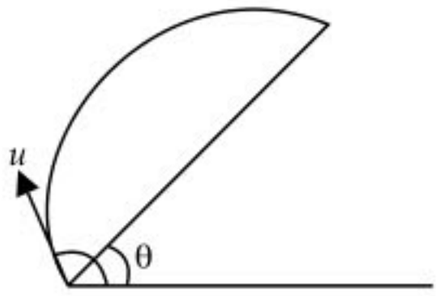
Maximum horizontal range is attained at $\theta = 45°$ and its value is

$$R_{max} = \frac{u^2}{g}$$

Velocity after time t,

$v_x = u\cos\theta,\ v_y = u\sin\theta - gt$

Projectile given angular projection



In case of a projectile projected with velocity u at an angle θ with the horizontal.

When a projectile is projected with velocity u, making an angle θ with the horizontal direction up the inclined plane, whose inclination with the horizontal direction is θ_0, then

- Range of projectile along the inclined plane is $R = \frac{u^2}{g\cos^2\theta_0}[\sin(2\theta - \theta_0) - \sin\theta_0]$.
- Time of flight on the inclined plane is $T = \frac{2u\sin(\theta - \theta_0)}{g\cos\theta_0}$.
- The maximum range on inclined plane is $R_{max} = \frac{u^2}{g(1+\sin\theta_0)}$.
- The angle at which the horizontal range on the inclined plane becomes maximum is given as, $\theta = \frac{\pi}{4} + \frac{\theta_0}{2}$.

Uniform Circular Motion

In this case, object moves in a circular path with a constant speed, it covers equal distances on circumference is equal intervals of time.

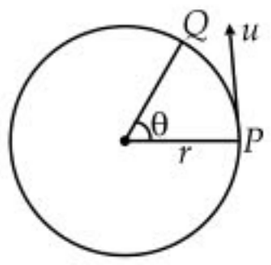
Centripetal force : It is the force acting on the object undergoing uniform circular motion.

Centripetal Acceleration : It is the acceleration acting on the object undergoing circular motion.

$$a = \frac{v^2}{r} = w^2r$$

Where ω is angular speed of the object.

It acts along the radius and is directed towards the centre of the circular path.



Angular displacement, $\theta = \frac{PQ}{r}$

Angular velocity, $w = \frac{d\theta}{dt}$

Linear velocity, $v = wr$

Angular acceleration, $\alpha = \frac{dw}{dt}$

Linear acceleration, $a = \alpha a$

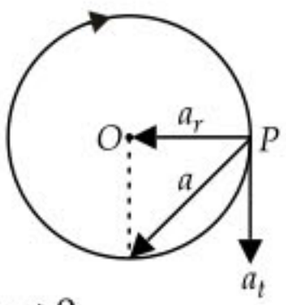
Tangential Acceleration and Radial Acceleration

Acceleration of an object in circular motion (or motion along any curved path) has two components :

- **Tangential acceleration :** The tangential acceleration arises from the change in the speed of an object and has a magnitude given by $a_t = \frac{d|\vec{v}|}{dt}$
- **Radial acceleration :** The radial acceleration is due to the change in direction of the velocity and is given by

$$a_r = \frac{v^2}{r} = \omega^2 r$$

As a_t and a_r are perpendicular to each other as shown in figure.



$\therefore$ Net acceleration, $|\vec{a}| = \sqrt{a_t^2 + a_r^2}$

In uniform circular motion, $a_t = 0$ but $a_r \neq 0$

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EXAM DRILL

1. $\vec{A}$ and $\vec{B}$ are two vectors of equal magnitude and θ is the angle between them. The angle between $\vec{A}$ or $\vec{B}$ with their resultant is

(a) $\frac{\theta}{4}$ (b) $\frac{\theta}{2}$ (c) 2θ (d) θ

2. A particle is moving along a circular path of radius 5 m with uniform speed of 5 m s^{-1}. What will be average acceleration when the particle completes half revolution?

(a) zero (b) 10 m s^{-2}

(c) 10π m s^{-2} (d) $\frac{10}{\pi}$ m s^{-2}

3. A vector $\vec{A}$ is along the positive z-axis and its vector product with another vector $\vec{B}$ is zero, then vector $\vec{B}$ could be

(a) $\hat{i}+\hat{j}$ (b) $4\hat{i}$ (c) $\hat{j}+\hat{k}$ (d) $-7\hat{k}$

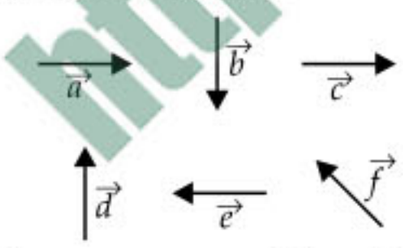
4. When the angle of projection is 75°, a ball falls 10 m short of the target. When the angle of projection is 45°, it falls 10 m ahead of the target. Both are projected from the same point with the same speed in the same direction, the distance of the target from the point of projection is

(a) 15 m (b) 30 m (c) 45 m (d) 10 m

5. A coastguard ship locates a pirate ship at a distance 560 m. It fires a cannon ball with an initial speed 82 m s^{-1}. At what angle from horizontal the ball must be fired so that it hits the pirate ship?
(Take $g = 10$ m s^{-2})

(a) 54° (b) 125° (c) 28° (d) 18°

6. Six vectors, $\vec{a}$ through $\vec{f}$ have the magnitudes and directions indicated in the figure. Which of the following statements is true?



(a) $\vec{b}+\vec{c}=\vec{f}$ (b) $\vec{d}+\vec{c}=\vec{f}$

(c) $\vec{d}+\vec{e}=\vec{f}$ (d) $\vec{b}+\vec{e}=\vec{f}$

7. A man standing on a road has to hold his umbrella at 30° with the vertical to keep the rain away. He throws the umbrella and starts running at 10 km h^{-1}. He finds that raindrops are hitting his head vertically. The actual speed of raindrops is

(a) 20 km h^{-1} (b) $10\sqrt{3}$ km h^{-1}

(c) $20\sqrt{3}$ km h^{-1} (d) 10 km h^{-1}

8. Resultant of two vectors $\vec{A}$ and $\vec{B}$ is of magnitude P. If $\vec{B}$ is reversed, then resultant is of magnitude Q. What is the value of $P^2 + Q^2$?

(a) $2(A^2 + B^2)$ (b) $2(A^2 - B^2)$

(c) $A^2 - B^2$ (d) $A^2 + B^2$

9. In a two dimensional motion, instantaneous speed v_0 is a positive constant. Then which of the following are necessarily true?

(a) The acceleration of the particle is zero.
(b) The acceleration of the particle is bounded.
(c) The acceleration of the particle is necessarily in the plane of motion.
(d) The particle must be undergoing a uniform circular motion.

10. A hiker stands on the edge of a cliff 490 m above the ground and throws a stone horizontally with an initial speed of 15 m s^{-1}. Neglect air resistance. With what speed the stone hits the ground?

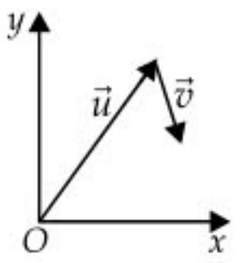
(a) 15 m s^{-1} (b) 90 m s^{-1}

(c) 99 m s^{-1} (d) 49 m s^{-1}

11. The horizontal range of a projectile fired at an angle of 15° is 50 m. If it is fired with the same speed at an angle of 45°, its range will be

(a) 60 m (b) 71 m (c) 100 m (d) 141 m

12. Figure shows the orientation of two vectors $\vec{u}$ and $\vec{v}$ in the xy plane.



If $\vec{u} = a\hat{i}+b\hat{j}$ and $\vec{v} = p\hat{i}+q\hat{j}$
which of the following is correct?

(a) a and p are positive while b and q are negative.
(b) a, p and b are positive while q is negative.
(c) a, q and b are positive while p is negative.
(d) a, b, p and q are all positive.

13. Let the resultant of two vectors $\vec{A}$ and $\vec{B}$ be $\vec{R}$. Let the angle between $\vec{A}$ and $\vec{R}$ be α and the angle between $\vec{B}$ and $\vec{R}$ be β. Let the magnitudes of $\vec{A}$, $\vec{B}$ and $\vec{R}$ be represented by A, B and R respectively. Which of the following statements is not correct?

(a) $\frac{R}{\sin(\alpha+\beta)} = \frac{A}{\sin\alpha} = \frac{B}{\sin\beta}$ (b) $R\sin\alpha = B\sin(\alpha+\beta)$

(c) $A\sin\alpha = B\sin\beta$ (d) $R\sin\beta = A\sin(\alpha+\beta)$

14. An insect trapped in a circular groove of radius 12 cm moves along the groove steadily and completes 7 revolutions in 100 s. What is the linear speed of the insect?

(a) 4.3 cm s^{-1} (b) 5.3 cm s^{-1}

(c) 6.3 cm s^{-1} (d) 7.3 cm s^{-1}

15. In a two dimensional motion, instantaneous speed v_0 is a positive constant. Then which of the following are necessarily true?

(a) The averge velocity is not zero at any time.
(b) Average acceleration must always vanish.
(c) Displacements in equal time intervals are equal.
(d) Equal path lengths are traversed in equal intervals.

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16. Which of the following statements is correct about the average velocity of a particle?

(a) $\vec{v}_{\text{average}} = \dfrac{\vec{v}(t_2) - \vec{v}(t_1)}{2}$

(b) $\vec{v}_{\text{average}} = \vec{a}_{\text{average}}(t_2 - t_1)$

(c) $\vec{v}_{\text{average}} = \dfrac{\vec{v}(t_2) + \vec{v}(t_1)}{2}$

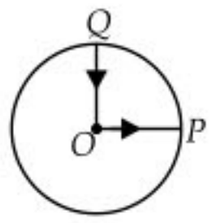
(d) $\vec{v}_{\text{average}} = \dfrac{\vec{r}(t_2) - \vec{r}(t_1)}{t_2 - t_1}$

(The average stands for average of the quantity over the time interval t_1 to t_2)

17. A cyclist starts from the centre O of a circular park of radius 1 km, reaches the edge P of the park, then cycles along the circumference and returns to the centre along QO as shown in the figure. If the round trip takes ten minutes, the net displacement and average speed of the cyclist (in metre and kilometre per hour) is

(a) 0, 1 (b) $\dfrac{\pi+4}{2}$, 0

(c) $21.4, \dfrac{\pi+4}{2}$ (d) 0, 21.4



18. Suppose that two objects A and B are moving with velocities $\vec{v}_A$ and $\vec{v}_B$ (each with respect to some common frame of reference). Let $\vec{v}_{AB}$ represent the velocity of A with respect to B. Then

(a) $\vec{v}_{AB} + \vec{v}_{BA} = 0$ (b) $\vec{v}_{AB} - \vec{v}_{BA} = 0$

(c) $\vec{v}_{AB} = \vec{v}_A + \vec{v}_B$ (d) $|\vec{v}_{AB}| \neq |\vec{v}_{BA}|$

19. The component of a vector $\vec{r}$ along x-axis will have maximum value if

(a) $\vec{r}$ is along positive y-axis

(b) $\vec{r}$ is along positive x-axis

(c) $\vec{r}$ makes an angle of 45° with the x-axis

(d) $\vec{r}$ is along negative y-axis

20. For a particle performing uniform circular motion, choose the incorrect statement from the following.

(a) Magnitude of particle velocity (speed)remains constant.

(b) Particle velocity remains directed perpendicular to radius vector.

(c) Direction of acceleration keeps changing as particle moves.

(d) Magnitude of acceleration does not remain constant.

21. A cyclist is riding with a speed of 27 km h^{-1}. As he approaches a circular turn on the road of radius 80 m, he applies brakes and reduces his speed at the constant rate of 0.50 m s^{-1} every second. What is the magnitude of the net acceleration of the cyclist on the circular turn?

(a) 0.68 m s^{-2} (b) 0.86 m s^{-2}

(c) 0.56 m s^{-2} (d) 0.76 m s^{-2}

22. For two vectors $\vec{A}$ and $\vec{B}$, $|\vec{A} + \vec{B}| = |\vec{A} - \vec{B}|$ is always true when

(a) $|\vec{A}| = |\vec{B}| \neq 0$

(b) $\vec{A} \perp \vec{B}$

(c) $|\vec{A}| = |\vec{B}| \neq 0$ and $\vec{A}$ and $\vec{B}$ are parallel

(d) $|\vec{A}| = |\vec{B}| \neq 0$ and $\vec{A}$ and $\vec{B}$ are antiparallel

23. A fighter plane is flying horizontally at an altitude of 1.5 km with speed 720 km h^{-1}. At what angle of sight (w.r.t. horizontal) when the target is seen, should the pilot drop the bomb in order to attack the target? (Take g = 10 m s^{-2}, tan23° = 0.43)

(a) 23° (b) 32° (c) 12° (d) 42°

24. Two particles are projected in air with speed u at angles θ_1 and θ_2 (both acute) to the horizontal, respectively. If the height reached by the first particle is greater than that of the second, then which one of the following is correct?

(a) $\theta_1 > \theta_2$ (b) $\theta_1 = \theta_2$

(c) $T_1 < T_2$ (d) $T_1 = T_2$

where T_1 and T_2 are the time of flight

25. A projectile is thrown with a velocity of $10\sqrt{2}$ m s^{-1} at an angle of 45° with horizontal. The interval between the moments when speed is $\sqrt{125}$ m s^{-1} is (Take g = 10 m s^{-2})

(a) 1.0 s (b) 1.5 s (c) 2.0 s (d) 0.5 s

26. A body is projected vertically upwards at time $t = 0$ and it is seen at a height H at time t_1 and t_2 seconds during its flight. The maximum height attained is (g is acceleration due to gravity)

(a) $\dfrac{g(t_2 - t_1)^2}{8}$ (b) $\dfrac{g(t_1 + t_2)^2}{4}$

(c) $\dfrac{g(t_1 + t_2)^2}{8}$ (d) $\dfrac{g(t_2 - t_1)^2}{4}$

27. If the scalar and vector products of two vectors $\vec{A}, \vec{B}$ are equal in magnitude, then the angle between the two vectors is

(a) 45° (b) 90° (c) 180° (d) 360°

28. The maximum range of projectile fired with some initial velocity is found to be 1000 m, in the absence of wind and air resistance. The maximum height reached by the projectile is

(a) 250 m (b) 500 m (c) 1000 m (d) 2000 m

29. To a man moving due north with a speed 5 m s^{-1}, the rain appears to fall vertically. When the man doubles his speed, the rain appears to fall at 60°. Find the actual speed of the rain and its direction.

(a) 10 m s^{-1}, 120° (b) 10 m s^{-1}, 180°

(c) 10 m s^{-1}, 90° (d) 10 m s^{-1}, 60°

30. A projectile is fired at an angle of 30° to the horizontal such that the vertical component of its initial velocity is 80 m s^{-1}. Its time to flight is T. Its velocity at $t = \dfrac{T}{4}$ has a magnitude of nearly

(a) 124 m s^{-1} (b) 134 m s^{-1}

(c) 144 m s^{-1} (d) 154 m s^{-1}

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31. The angle between $\vec{A} = \hat{i} + \hat{j}$ and $\vec{B} = \hat{i} - \hat{j}$ is

(a) 45° (b) 90° (c) –45° (d) 180°

32. The position of a particle is given by
$\vec{r} = 3.0t\,\hat{i} + 2.0t^2\,\hat{j} + 5.0\hat{k}$
where t is in seconds and the coefficients have the proper units for $\vec{r}$ to be in metres.
What is the magnitude and direction of velocity of the particle at $t = 1$ s ?

(a) 5 m s^{-1}, $\tan^{-1}\left(\frac{4}{3}\right)$ with x-axis.

(b) 5 m s^{-1}, $\tan^{-1}\left(\frac{3}{4}\right)$ with x-axis.

(c) 4 m s^{-1}, $\tan^{-1}\left(\frac{3}{4}\right)$ with x-axis.

(d) 4 m s^{-1}, $\tan^{-1}\left(\frac{4}{3}\right)$ with x-axis.

33. Consider the quantities, pressure, power, energy, impulse, gravitational potential, electrical charge, temperature, acceleration. Out of these, the only vector quantities are

(a) impulse, pressure and acceleration
(b) impulse and acceleration
(c) acceleration and gravitational potential
(d) impulse and pressure

34. The component of vector $\vec{A} = 2\hat{i} + 3\hat{j}$ along the direction of $(\hat{i} + \hat{j})$ is

(a) $\frac{1}{\sqrt{2}}$ (b) $\frac{3}{\sqrt{2}}$ (c) $\frac{5}{\sqrt{2}}$ (d) $\frac{7}{\sqrt{2}}$

35. Which one of the following statements is true?

(a) A scalar quantity is the one that is conserved in a process.
(b) A scalar quantity is the one that can never take negative values.
(c) A scalar quantity is the one that does not vary from one point to another in space.
(d) A scalar quantity has the same value for observers with different orientations of the axes.

36. Rain is falling vertically with a speed of 30 m s^{-1}. A woman rides a bicycle with a speed of 12 m s^{-1} in east to west direction. What is the direction in which she should hold her umbrella?

(a) At an angle of $\tan^{-1}\left(\frac{2}{5}\right)$ with the vertical towards the east.

(b) At angle of $\tan^{-1}\left(\frac{2}{5}\right)$ with the vertical towards the west.

(c) At angle of $\tan^{-1}\left(\frac{5}{2}\right)$ with the vertical towards the east.

(d) At angle of $\tan^{-1}\left(\frac{5}{2}\right)$ with the vertical towards the west.

37. A particle starts from origin at $t = 0$, with a velocity $5.0\hat{i}$ m s^{-1} and moves in x-y plane under action of a force which produces a constant acceleration of $3.0\hat{i} + 2.0\hat{j}$ m s^{-2}. What is the y-coordinate of the particle at the instant its x-coordinate is 84 m?

(a) 36 m (b) 48 m
(c) 84 m (d) 126 m

38. If $|\vec{A}| = 2$ and $|\vec{B}| = 4$, then match the relations in column I with the angle θ between $\vec{A}$ and $\vec{B}$ in column II.

Column I		Column II	
(A)	$\lvert\vec{A}\times\vec{B}\rvert = 0$	(p)	$\theta = 30°$
(B)	$\lvert\vec{A}\times\vec{B}\rvert = 8$	(q)	$\theta = 45°$
(C)	$\lvert\vec{A}\times\vec{B}\rvert = 4$	(r)	$\theta = 90°$
(D)	$\lvert\vec{A}\times\vec{B}\rvert = 4\sqrt{2}$	(s)	$\theta = 0°$

(a) A → p, B → r, C → q, D → s
(b) A → r, B → q, C → s, D → p
(c) A → s, B → r, C → p, D → q
(d) A → q, B → p, C → r, D → s

39. From an elevated point P, a stone is projected vertically upwards. When the stone reaches a distance h below P, its velocity is double of its velocity at a height h above P. The greatest height attained by the stone from the point of projection P is

(a) $\frac{3}{5}h$ (b) $\frac{5}{3}h$
(c) $\frac{7}{5}h$ (d) $\frac{5}{7}h$

40. A body projected at an angle with the horizontal has a range 300 m. If the time of flight is 6 s, then the horizontal component of velocity is

(a) 30 m s^{-1} (b) 50 m s^{-1}
(c) 40 m s^{-1} (d) 45 m s^{-1}

41. In a uniform circular motion, the angle between the velocity and acceleration is

(a) 0° (b) 45°
(c) 60° (d) 90°

42. On a two lane road, car A is travelling with a speed of 36 km h^{-1}. Two cars B and C approach car A in opposite directions with a speed of 54 km h^{-1} each. At a certain instant, when the distance AB is equal to AC, both being 1 km, B decides to overtake A before C does. What minimum acceleration of car B is required to avoid an accident?

(a) 9.8 m s^{-2} (b) 10 m s^{-2}
(c) 1 m s^{-2} (d) 2 m s^{-2}

43. In a lift moving up with an acceleration of 5 m s^{-2}, a ball is dropped from a height of 1.25 m. The time taken by the ball to reach the floor of the lift is ..... (nearly) (g = 10 m s^{-2})

(a) 0.3 second (b) 0.2 second
(c) 0.16 second (d) 0.4 second

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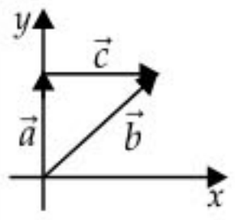
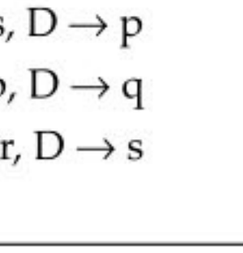
44. A projectile is projected at 10 m s^{-1} by making at an angle 60° to the horizontal. After some time its velocity makes an angle of 30° to the horizontal. Its speed at this instant is

(a) $\frac{10}{\sqrt{3}}$ (b) $10\sqrt{3}$

(c) $\frac{5}{\sqrt{3}}$ (d) $5\sqrt{3}$

45. Given below in column I are the relations between vectors $\vec{a}, \vec{b}$ and $\vec{c}$ and in column II are the orientations of $\vec{a}, \vec{b}$ and $\vec{c}$ in the xy plane. Match the relation in column I to correct orientations in column II.

	Column I		Column II
(A)	$\vec{a}+\vec{b}=\vec{c}$	(p)	
(B)	$\vec{a}-\vec{c}=\vec{b}$	(q)	
(C)	$\vec{b}-\vec{a}=\vec{c}$	(r)	
(D)	$\vec{a}+\vec{b}+\vec{c}=0$	(s)	

(a) A → r, B → s, C → q, D → p

(b) A → q, B → r, C → s, D → p

(c) A → s, B → r, C → p, D → q

(d) A → p, B → q, C → r, D → s

DAY 03 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ

Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____

(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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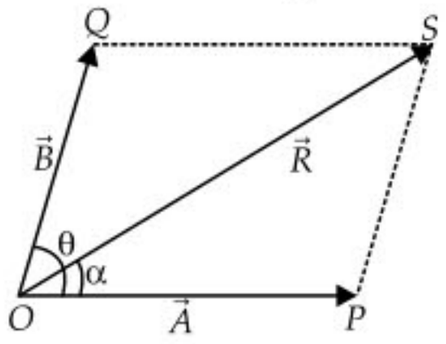
HINTS & SOLUTIONS

1. (b): Here, $|\vec{A}| = |\vec{B}|$

Let the resultant $\vec{R}$ makes an angle α with the vector $\vec{A}$.



Then

$$\tan\alpha = \frac{B\sin\theta}{A + B\cos\theta} = \frac{A\sin\theta}{A + A\cos\theta} \quad (\because |\vec{A}| = |\vec{B}| \text{ Given})$$

$$= \frac{\sin\theta}{1+\cos\theta} = \frac{2\sin\frac{\theta}{2}\cos\frac{\theta}{2}}{2\cos^2\frac{\theta}{2}} = \tan\frac{\theta}{2}$$

$$\alpha = \frac{\theta}{2}$$

2. (d): Change in velocity when the particle completes half revolution is

$\Delta v = 5 \text{ m s}^{-1} - (-5 \text{ m s}^{-1}) = 10 \text{ m s}^{-1}$

Time taken to complete the half revolution is

$$t = \frac{\pi r}{v} = \frac{\pi \times 5 \text{ m}}{5 \text{ m s}^{-1}} = \pi \text{ s}$$

$$\text{Average acceleration} = \frac{\Delta v}{t} = \frac{10 \text{ m s}^{-1}}{\pi \text{ s}} = \frac{10}{\pi} \text{ m s}^{-2}$$

3. (d): The vector product of two non-zero vectors is zero if they are in the same direction or in the opposite direction. Hence vector $\vec{B}$ must be parallel or antiparallel to vector $\vec{A}$, *i.e.* along $\pm z$-axis.

4. (b): Let d be distance of the target from the point of projection.

$$\therefore \quad \frac{u^2 \sin(2\times 75°)}{g} = d - 10$$

$$\text{or} \quad \frac{u^2}{2g} = d - 10 \qquad \ldots(\text{i})$$

$$\text{and} \quad \frac{u^2 \sin(2\times 45°)}{g} = d + 10$$

$$\text{or} \quad \frac{u^2}{g} = d + 10 \qquad \ldots(\text{ii})$$

Divide (i) by (ii), we get

$$\frac{d-10}{d+10} = \frac{1}{2} \quad \text{or} \quad d = 30 \text{ m}$$

5. (c): $\text{Range} = \dfrac{u^2 \sin 2\theta}{g}$

$$\therefore \quad 560 = \frac{(82)^2 \sin 2\theta}{10}$$

$$\text{or} \quad \sin 2\theta = \frac{5600}{(82)^2} = 0.832$$

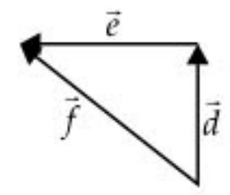
$$\text{or} \quad 2\theta = \sin^{-1}(0.832) = 56.30° \qquad [\sin 56.30° = 0.832]$$

$$\Rightarrow \quad \theta \approx 28°$$

6. (c): As per the laws of vector addition,

$\vec{d} + \vec{e} = \vec{f}$

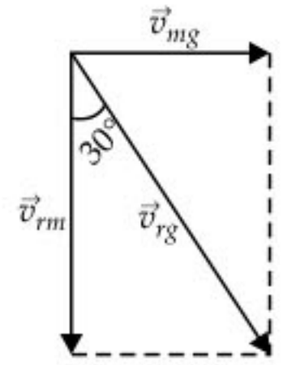
This is as shown in adjacent figure.



7. (a): When the man is at rest with respect to the ground, the rain comes to him at an angle 30° with the vertical. This is the direction of the velocity of raindrops with respect to the ground.

Here, $\vec{v}_{rg}$ = velocity of the rain with respect to the ground.

From figure,



$$\sin 30° = \frac{v_{mg}}{v_{rg}}$$

$$\text{or} \quad v_{rg} = \frac{v_{mg}}{\sin 30°}$$

$$= \frac{10 \text{ km h}^{-1}}{(1/2)} = 20 \text{ km h}^{-1}$$

8. (a): Let θ be angle between $\vec{A}$ and $\vec{B}$.

$\therefore$ Resultant of $\vec{A}$ and $\vec{B}$ is

$$P = \sqrt{A^2 + B^2 + 2AB\cos\theta} \qquad \ldots(\text{i})$$

When $\vec{B}$ is reversed, then the angle between $\vec{A}$ and $-\vec{B}$ is $(180° - \theta)$.

$\therefore$ Resultant of $\vec{A}$ and $-\vec{B}$ is

$$Q = \sqrt{A^2 + B^2 + 2AB\cos(180° - \theta)}$$

$$Q = \sqrt{A^2 + B^2 - 2AB\cos\theta} \qquad \ldots(\text{ii})$$

Squaring and adding (i) and (ii), we get

$P^2 + Q^2 = 2(A^2 + B^2)$

9. (c)

10. (c): Here, $u = 15 \text{ m s}^{-1}$, $h = 490 \text{ m}$

Time taken by the stone to reach the ground is

$$t = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2\times 490 \text{ m}}{9.8 \text{ m s}^{-2}}} = 10 \text{ s}$$

Motion along horizontal direction,

$u_x = 15 \text{ m s}^{-1}$, $a_x = 0$

$v_x = u_x + a_x t = 15 + 0 \times 10 = 15 \text{ m s}^{-1}$

Motion along vertical direction

$u_y = 0$, $a_y = g$

$v_y = u_y + a_y t = 0 + 9.8 \times 10 = 98 \text{ m s}^{-1}$

$\therefore$ Speed of the stone when it hits the ground is

$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{(15)^2 + (98)^2} = 99 \text{ m s}^{-1}$$

11. (c): Horizontal range, $R = \dfrac{u^2 \sin 2\theta}{g}$

For the same speed,

$R \propto \sin 2\theta$

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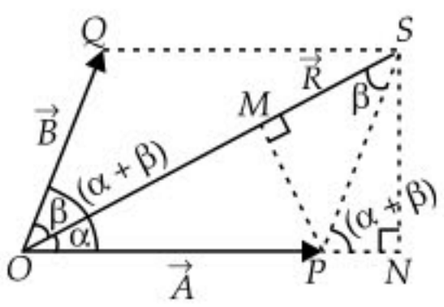
$$\therefore \quad \frac{R_1}{R_2} = \frac{\sin 2\times 15^\circ}{\sin 2\times 45^\circ} = \frac{\sin 30^\circ}{\sin 90^\circ}$$

$$\text{or} \quad R_2 = R_1 \frac{\sin 90^\circ}{\sin 30^\circ} = 50\text{ m} \times \frac{1}{\left(\frac{1}{2}\right)} = 100\text{ m}$$

12. (b)

13. (a) :



Let OP and OQ represent two vectors $\vec{A}$ and $\vec{B}$ making an angle $(\alpha+\beta)$.
Using the parallelogram method of vector addition,
Resultant vector, $\vec{R} = \vec{A} + \vec{B}$
SN is normal to OP and PM is normal to OS
From the geometry of the figure,

$OS^2 = ON^2 + SN^2 = (OP + PN)^2 + SN^2$

$= (A + B\cos(\alpha+\beta))^2 + (B\sin(\alpha+\beta))^2$

$R^2 = A^2 + B^2 + 2AB\cos(\alpha+\beta)$

In ΔOSN, $SN = OS\sin\alpha = R\sin\alpha$

and in ΔPSN, $SN = PS\sin(\alpha+\beta) = B\sin(\alpha+\beta)$

$$\therefore \quad R\sin\alpha = B\sin(\alpha+\beta)$$

$$\text{or} \quad \frac{R}{\sin(\alpha+\beta)} = \frac{B}{\sin\alpha} \qquad \ldots(i)$$

Similarly,

$PM = A\sin\alpha = B\sin\beta$

$$\frac{A}{\sin\beta} = \frac{B}{\sin\alpha} \qquad \ldots(ii)$$

Combining (i) and (ii), we get

$$\frac{R}{\sin(\alpha+\beta)} = \frac{A}{\sin\beta} = \frac{B}{\sin\alpha} \qquad \ldots(iii)$$

From (iii)

$R\sin\beta = A\sin(\alpha+\beta)$

14. (b): Here, $r = 12$ cm

Frequency, $\upsilon = \frac{7}{100}$ Hz

The angular speed of the insect is

$$\omega = 2\pi\upsilon = 2\pi \times \frac{7}{100} = 0.44\text{ rad s}^{-1}$$

The linear speed of the insect is

$v = \omega r = 0.44 \times 12 = 5.3\text{ cm s}^{-1}$

15. (d)

16. (d)

17. (d): Net displacement of the cyclist = zero
Since the initial position coincides with the final position.
Average speed of the cyclist

$$= \frac{\text{Total distance travelled}}{\text{Total time taken}}$$

$$= \frac{OP + PQ + QO}{10}\text{km min}^{-1} = \frac{1 + \frac{\pi}{2}\times 1 + 1}{10}\text{km min}^{-1}$$

$$= \frac{\pi+4}{20}\text{km min}^{-1} = \frac{\pi+4}{20}\times 60\text{ km h}^{-1} = 21.4\text{ km h}^{-1}$$

18. (a): Velocity of object A relative to that of B is

$\vec{v}_{AB} = \vec{v}_A - \vec{v}_B$

Velocity of object B relative to that of A is

$\vec{v}_{BA} = \vec{v}_B - \vec{v}_A$

$\therefore \quad \vec{v}_{AB} = -\vec{v}_{BA}$

and $\quad |\vec{v}_{AB}| = |\vec{v}_{BA}|$

19. (b)

20. (d): For a particle performing uniform circular motion, magnitude of the acceleration remains constant.

21. (b): Here, $v = 27\text{ km h}^{-1} = 27 \times \frac{5}{18}\text{ m s}^{-1}$

$= \frac{15}{2}\text{ m s}^{-1} = 7.5\text{ m s}^{-1}$

$r = 80$ m

Centripetal acceleration, $a_c = \frac{v^2}{r}$

$$a_c = \frac{(7.5\text{ m s}^{-1})^2}{80\text{ m}} = 0.7\text{ m s}^{-2}$$

Tangential acceleration, $a_t = 0.5\text{ m s}^{-2}$
Magnitude of the net acceleration is

$$a = \sqrt{(a_c)^2 + (a_t)^2} = \sqrt{(0.7)^2 + (0.5)^2} = 0.86\text{ m s}^{-2}$$

22. (b): Let θ be the angle between the vectors $\vec{A}$ and $\vec{B}$.

$|\vec{A} + \vec{B}| = \sqrt{|\vec{A}|^2 + |\vec{B}|^2 + 2|\vec{A}||\vec{B}|\cos\theta}$

$|\vec{A} - \vec{B}| = \sqrt{|\vec{A}|^2 + |\vec{B}|^2 - 2|\vec{A}||\vec{B}|\cos\theta}$

According to given problem

$|\vec{A} + \vec{B}| = |\vec{A} - \vec{B}|$

$\sqrt{|\vec{A}|^2 + |\vec{B}|^2 + 2|\vec{A}||\vec{B}|\cos\theta}$

$= \sqrt{|\vec{A}|^2 + |\vec{B}|^2 - 2|\vec{A}||\vec{B}|\cos\theta}$

Squaring both sides, we get

$|\vec{A}|^2 + |\vec{B}|^2 + 2|\vec{A}||\vec{B}|\cos\theta$

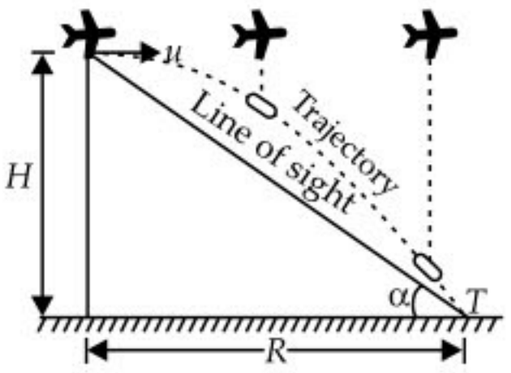
$= |\vec{A}|^2 + |\vec{B}|^2 - 2|\vec{A}||\vec{B}|\cos\theta$

$4|\vec{A}||\vec{B}|\cos\theta = 0$

$\cos\theta = 0 \quad \text{or} \quad \theta = \cos^{-1}(0) = \frac{\pi}{2}$

i.e. the vectors $\vec{A}$ and $\vec{B}$ are perpendicular to each other.

23. (a) :



Here, $u = 720\text{ km h}^{-1}$

$= 720 \times \frac{5}{18}\text{ m s}^{-1} = 200\text{ m s}^{-1}$

$H = 1.5\text{ km} = 1.5 \times 1000\text{ m} = 1500\text{ m}$

Time taken by the bomb to attack the target

$$t = \sqrt{\frac{2H}{g}} = \sqrt{\frac{2\times 1500\text{ m}}{10\text{ m s}^{-2}}} = \sqrt{300}\text{ s} = 10\sqrt{3}\text{ s}$$

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$R = u \times t = 200 \text{ m s}^{-1} \times 10\sqrt{3} \text{ s} = 2000\sqrt{3} \text{ m}$

From figure,

Angle of sight (w.r.t horizontal) $\alpha = \tan^{-1}\left(\frac{H}{R}\right)$

$\alpha = \tan^{-1}\left(\frac{1500}{2000\sqrt{3}}\right) = \tan^{-1}\left(\frac{3}{4\sqrt{3}}\right) = \tan^{-1}\left(\frac{\sqrt{3}}{4}\right)$

$\alpha = \tan^{-1}(0.43)$ or $\alpha = 23°$

24. (a) : Height, $H = \frac{u^2 \sin^2\theta}{2g}$

For the same speed

$H \propto \sin^2\theta$

$\because \quad H_1 > H_2$ (Given)

$\therefore \quad \sin^2\theta_1 > \sin^2\theta_2$

or $\theta_1 > \theta_2$ ...(i)

Time of flight, $T = \frac{2u\sin\theta}{g}$

For the same speed

$T \propto \sin\theta$

$\because \quad \theta_1 > \theta_2$ (From (i))

$\therefore \quad \sin\theta_1 > \sin\theta_2 \Rightarrow \quad T_1 > T_2$

25. (a) : Let the speed of the projectile be $v\left(=\sqrt{125} \text{ m s}^{-1}\right)$ at time t. Then

$v^2 = v_x^2 + v_y^2$

Here, $v_x = u_x = u\cos 45° = 10\sqrt{2} \times \frac{1}{\sqrt{2}} = 10 \text{ m s}^{-1}$ ...(i)

and $v_y = u_y - gt$

$v_y = u\sin 45° - 10t$

$= 10\sqrt{2} \times \frac{1}{\sqrt{2}} - 10t = 10 - 10t$ ...(ii)

Squaring and adding (i) and (ii), we get

$v_x^2 + v_y^2 = (10)^2 + (10 - 10t)^2$

$\left(\sqrt{125}\right)^2 = (10)^2 + (10 - 10t)^2$

or $(10 - 10t)^2 = 125 - 100 = 25$

or $(10 - 10t) = \pm 5$

Hence, $t_1 = \frac{10-5}{10}$ and $t_2 = \frac{10+5}{10}$

$\therefore \quad t_2 - t_1 = \left(\frac{10+5}{10}\right) - \left(\frac{10-5}{10}\right) = 1 \text{ s}$

26. (c) : Time taken for the body to reach the highest point is $\frac{t_1 + t_2}{2}$.

As $v = u - gt$

At highest point, $v = 0$

Therefore, initial velocity of the body is

$u = \frac{g(t_1 + t_2)}{2}$

Maximum height attained by the body is

$H_{max} = \frac{u^2}{2g} = \frac{1}{2g}\left(\frac{g(t_1 + t_2)}{2}\right)^2 = \frac{g(t_1 + t_2)^2}{8}$

27. (a) : Let θ be angle between vectors $\vec{A}$ and $\vec{B}$. Given, $|\vec{A} \times \vec{B}| = |\vec{A} \cdot \vec{B}|$

$\therefore \quad AB\sin\theta = AB\cos\theta$

or $\tan\theta = 1$ or $\theta = 45°$

28. (a) : Range, $R = \frac{u^2 \sin 2\theta}{g}$

For maximum range, angle of projection θ is 45°.

$\therefore \quad R_{max} = \frac{u^2 \sin(2 \times 45°)}{g} = \frac{u^2}{g} = 1000 \text{ m}$ ...(i)

$\therefore$ Maximum height, $H = \frac{u^2 \sin^2 45°}{2g}$

$H = \frac{1}{2} \times 1000 \times \left(\frac{1}{\sqrt{2}}\right)^2 = 250 \text{ m}$ (Using (i))

29. (a) : Let $\vec{v}_r = v_{rx}\hat{i} + v_{ry}\hat{j}$ and $\vec{v}_m = 5\hat{i}$ (in 1st case)

$\vec{v}_{rm} = (v_{rx} - v_m)\hat{i} + v_{ry}\hat{j}$

Case (i) : $\tan 90° = \frac{v_{ry}}{v_{rx} - 5}$ or $v_{rx} = 5 \text{ m s}^{-1}$

Case (ii) : $\vec{v}_{rm} = (5\hat{i} - 10\hat{i}) + v_{ry}\hat{j} \quad \left(\because \ \vec{v}_m = 10\hat{i}\right)$

$\tan 60° = \frac{v_{ry}}{5 - 10}$ or $v_{ry} = -5\sqrt{3}$

$\vec{v}_r = 5\hat{i} - 5\sqrt{3}\hat{j}$

$|\vec{v}_r| = 10 \text{ m s}^{-1}$

$\angle\phi = \tan^{-1}\left(\frac{-5\sqrt{3}}{5}\right)$ or $\phi = 120°$

30. (c) : Vertical component of initial velocity,

$u_y = u\sin 30°$

or $u = \frac{u_y}{\sin 30°} = \frac{80}{(1/2)} = 160 \text{ m s}^{-1}$

$(\because \ u_y = 80 \text{ m s}^{-1}$ (Given))

Horizontal component of initial velocity,

$u_x = u\cos 30° = 160 \times \frac{\sqrt{3}}{2} = 80\sqrt{3} \text{ m s}^{-1}$

Time of flight,

$T = \frac{2u\sin\theta}{g} = \frac{2 \times 160 \times \sin 30°}{10} = 16 \text{ s}$

$\therefore \quad t = \frac{T}{4} = \frac{16}{4} = 4 \text{ s}$

Let v be the velocity of the projectile at $t = \frac{T}{4}$.

Its horizontal and vertical components are given by

$v_x = u_x = 80\sqrt{3} \text{ m s}^{-1}$

$v_y = u_y - gt = 80 - 10 \times 4 = 40 \text{ m s}^{-1}$

Its magnitude is given by

$v = \sqrt{v_x^2 + v_y^2} = \sqrt{\left(80\sqrt{3}\right)^2 + (40)^2}$

$= 40\sqrt{12 + 1} = 40\sqrt{13} \approx 144 \text{ m s}^{-1}$

31. (b): Given : $\vec{A} = \hat{i} + \hat{j}$, $\vec{B} = \hat{i} - \hat{j}$

$\therefore \quad |\vec{A}| = \sqrt{(1)^2 + (1)^2} = \sqrt{2}$ and $|\vec{B}| = \sqrt{(1)^2 + (-1)^2} = \sqrt{2}$

Let θ be angle between the vectors $\vec{A}$ and $\vec{B}$. Then according to definition of scalar product (or dot product)

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$\vec{A}\cdot\vec{B}=|\vec{A}||\vec{B}|\cos\theta$

or $\cos\theta=\dfrac{\vec{A}\cdot\vec{B}}{|\vec{A}||\vec{B}|}=\dfrac{(\hat{i}+\hat{j})\cdot(\hat{i}-\hat{j})}{(2)(2)}=0$

$\therefore\quad \theta=\cos^{-1}(0)=90^\circ$

32. (a) : Given : $\vec{r}=3.0t\,\hat{i}+2.0t^2\,\hat{j}+5.0\hat{k}$

Velocity, $\vec{v}=\dfrac{d\vec{r}}{dt}=\dfrac{d}{dt}(3.0t\,\hat{i}+2.0t^2\,\hat{j}+5.0\hat{k})$

$=3.0\,\hat{i}+4.0t\,\hat{j}\ \text{m s}^{-1}$

At $t=1.0$ s, $\vec{v}=3.0\,\hat{i}+4.0\,\hat{j}\ \text{m s}^{-1}$

Magnitude of velocity is

$|\vec{v}|=\sqrt{(3)^2+(4)^2}=5\ \text{m s}^{-1}$

Let θ be angle which the direction of $\vec{v}$ makes with x-axis. Then

$\tan\theta=\dfrac{v_y}{v_x}=\dfrac{4}{3}$

$\theta=\tan^{-1}\left(\dfrac{4}{3}\right)$

33. (b): Among the given physical quantities pressure, power, energy, gravitational potential, electrical charge, temperature are scalar quantities whereas only impulse and acceleration are vector quantities.

34. (c) : Given : $\vec{A}=2\hat{i}+3\hat{j}$

$\vec{B}=\hat{i}+\hat{j}$

Component of $\vec{A}$ along the direction of $\vec{B}$ is

$=\dfrac{\vec{A}\cdot\vec{B}}{|\vec{B}|}=\dfrac{(2\hat{i}+3\hat{j})\cdot(\hat{i}+\hat{j})}{\sqrt{(1)^2+(1)^2}}=\dfrac{5}{\sqrt{2}}$

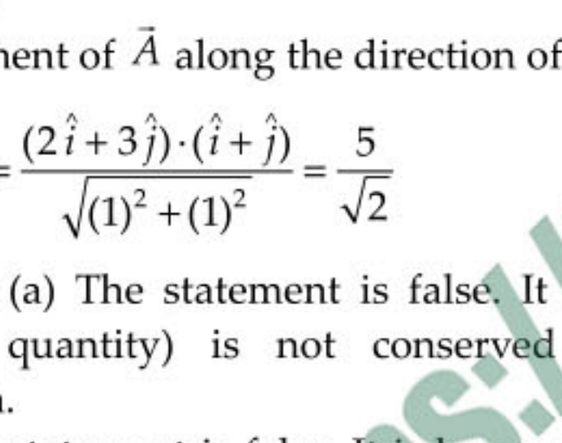
35. (d): (a) The statement is false. It is because energy (scalar quantity) is not conserved during inelastic collision.

(b) The statement is false. It is because the temperature (scalar quantity) can be negative.

(c) The statement is false. It is because gravitational potential energy (scalar quantity) vary from point to point in space.

(d) The statement is true because the value of scalar does not change with orientation of axes.

36. (b):



In figure, $\vec{v}_r$ represents the velocity of rain and $\vec{v}_b$, the velocity of the bicycle, the woman is riding. To protect herself from rain, the woman should hold her umbrella in the direction of relative velocity of rain with respect to the bicycle, $\vec{v}_{rb}$.

From figure,

$\tan\theta=\dfrac{v_b}{v_r}=\dfrac{12}{30}=\dfrac{2}{5}$ or $\theta=\tan^{-1}\left(\dfrac{2}{5}\right)$

Therefore, the woman should hold her umbrella at an angle of $\tan^{-1}\left(\dfrac{2}{5}\right)$ with the verical towards the west.

37. (a) : The position of the particle is given by

$\vec{r}=\vec{r}_0+\vec{v}_0t+\dfrac{1}{2}\vec{a}t^2$

where $\vec{r}_0$ is the position vector at $t=0$

$\vec{v}_0$ is the velocity at $t=0$

Here, $\vec{r}_0=0$, $\vec{v}_0=5.0\,\hat{i}\ \text{m s}^{-1}$, $\vec{a}=3.0\,\hat{i}+2.0\,\hat{j}\ \text{m s}^{-2}$

$\therefore\quad \vec{r}=(5.0\,\hat{i})t+\dfrac{1}{2}(3.0\,\hat{i}+2.0\,\hat{j})t^2$

$=(5.0t+1.5t^2)\,\hat{i}+1.0t^2\,\hat{j}$

$\therefore\quad x=5.0t+1.5t^2,\ y=1.0t^2$

Given : $x=84$ m

$\therefore\quad 84=5.0t+1.5t^2$

or $1.5t^2+5.0t-84=0$ or $3t^2+10t-168=0$

On solving, we get $t=6$ s

At $t=6$ s, $y=(1.0)(6)^2=36$ m

38. (c) : Here, $|\vec{A}|=2, |\vec{B}|=4$

As $|\vec{A}\times\vec{B}|=|\vec{A}||\vec{B}|\sin\theta$

(A) $|\vec{A}\times\vec{B}|=0$

$\because\quad |\vec{A}|\neq 0,\ |\vec{B}|\neq 0$

$\Rightarrow\quad \sin\theta=0$ or $\theta=0^\circ$

$A\rightarrow s$

(B) $|\vec{A}\times\vec{B}|=8$

$\Rightarrow\quad 8=(2)(4)\sin\theta$ or $\sin\theta=1$ or $\theta=90^\circ$

$B\rightarrow r$

(C) $|\vec{A}\times\vec{B}|=4$

$\Rightarrow\quad 4=(2)(4)\sin\theta$ or $\sin\theta=\dfrac{1}{2}$ or $\theta=30^\circ$

$C\rightarrow p$

(D) $|\vec{A}\times\vec{B}|=4\sqrt{2}$

$\Rightarrow\quad 4\sqrt{2}=(2)(4)\sin\theta$ or $\sin\theta=\dfrac{1}{\sqrt{2}}$ or $\theta=45^\circ$

$D\rightarrow q$

39. (b): From equation of motion

At above point P

$v^2=u^2-2gh$ ...(i)

At below point P

$(2v)^2=v^2+4gh$

$=u^2-2gh+4gh$

$(2v)^2=u^2+2gh$ ...(ii)

Adding equation (i) and (ii), we get

$5v^2=2u^2$

$u^2=\dfrac{5v^2}{2}$ ...(iii)

Subtracting equation (i) from equation (ii)

$v^2=\dfrac{4}{3}gh$ ...(iv)

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$\therefore$ Maximum height attained by stone is

$$H = \frac{u^2}{2g}$$

$$= \frac{\frac{5v^2}{2}}{2g} = \frac{\frac{5}{2}\left(\frac{4}{3}gh\right)}{2g} \quad \text{(using (iii) \& (iv))}$$

$$H = \frac{5}{3}h$$

40. (b): Horizontal range, $R = u\cos\theta \times t$
Here, $R = 300$ m, $t = 6$ s
Therefore, horizontal components of velocity.

$$u\cos\theta = \frac{R}{t} = \frac{300}{6} = 50 \text{ m s}^{-1}$$

41. (d): In uniform circular motion, velocity and acceleration are perpendicular to the plane of the circle.

42. (c) : Velocity of car A = 36 km h^{-1} = 10 m s^{-1}
Velocity of car B and car C = 54 km h^{-1} = 15 m s^{-1}
Relative velocity of car B w.r.t. car A
= 15 – 10 = 5 m s^{-1}
Relative velocity of car C w.r.t. car A
= 15 + 10 = 25 m s^{-1}
As, $AB = AC = 1$ km = 1000 m,
Time available to B or C for crossing A

$$= \frac{1000}{25} = 40 \text{ s}$$

If car B accelerates with acceleration a, to cross A before car C does, then
$u = 5$ m s^{-1}, $t = 40$ s,
$S = 1000$ m, $a = ?$

Using, $S = ut + \frac{1}{2}at^2$, we have

$$1000 = 5 \times 40 + \frac{1}{2}a \times 40 \times 40$$

or $1000 - 200 = 800a$ or $a = 1$ m s^{-2}

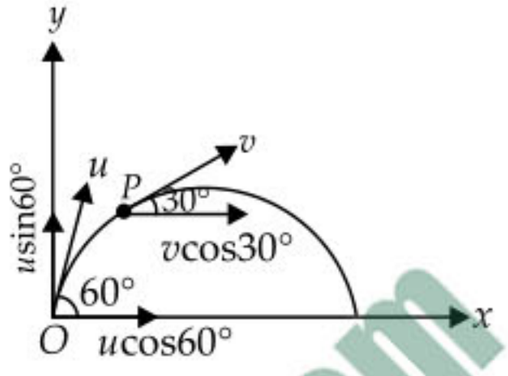
43. (d): Time taken by the ball to reach the floor of the lift is

$$t = \sqrt{\frac{2h}{a+g}}$$

Here, $h = 1.25$ m, $g = 10$ m s^{-2}, $a = 5$ m s^{-2}

$$\therefore \quad t = \sqrt{\frac{2 \times 1.25 \text{ m}}{(5+10) \text{ m s}^{-2}}} = 0.4 \text{ s}$$

44. (a) :

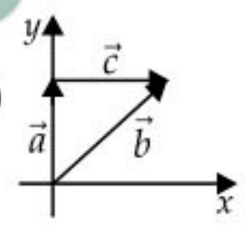


Let v be the velocity of the projectile at P when it makes an angle 30° with the horizontal.
Then

$$v\cos 30° = 4\cos 60° = 10 \times \frac{1}{2} = 5$$

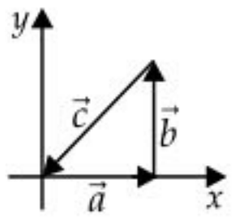
$$v = \frac{5}{\cos 30°} = \frac{5}{\sqrt{3}/2} = \frac{10}{\sqrt{3}} \text{ m s}^{-1}$$

45. (c) : (p)



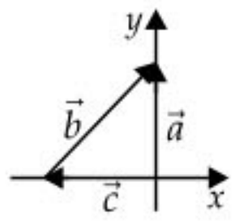
From figure,
$\vec{a} + \vec{c} = \vec{b}$ or $\vec{b} - \vec{a} = \vec{c}$
C → p

(q)



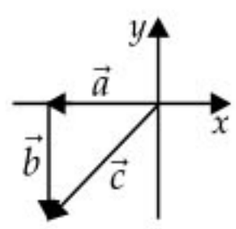
From figure,
$\vec{a} + \vec{b} + \vec{c} = 0$
D → q

(r)



From figure,
$\vec{c} + \vec{b} = \vec{a}$
or $\vec{a} - \vec{c} = \vec{b}$
B → r

(s)



From figure,
$\vec{a} + \vec{b} = \vec{c}$
A → s

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Laws of Motion

Force

It is an external effort in the form of a push or a pull which tries to produce motion in a body at rest and which tries to stop or stops a moving object or which tries to changes the direction of motion of the object.

Inertia

The property of a body by virtue at which the body resists a change in state of rest or uniform motion along a straight line is known as inertia.

Types of inertia

- Inertia of rest : It is the resistance of the body to change its state of rest.
- Inertia of Motion : It is the resistance of the body to change its state of motion.
- Inertia of direction : It is the resistance of the body to change its direction of motion.

Newton's first law of motion

According to this law, an object continues in a state of rest or in a state of motion at a constant speed along a straight line unless compelled to change that state by a net force.

Newton's second law of motion

According to this law, the rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction in which the force acts.

If an object a mass m is moving with an acceleration a under a force then

$a \propto F,\ a \propto \frac{1}{m}$

or $a = \frac{kF}{m} = \frac{k.P}{t}$ (where $p = mv$)

$\therefore\ F = ma$ ($\because k = 1$)

Momentum

It is the product of mass and velocity.

$P = mv$

Its SI unit is kg m s^{-1} and dimensional formula is $[MLT^{-1}]$

Impulse

The impulse of a force is the product of the force and the time interval over which it acts. It is a vector quantity.

Impulse = force × time duration

= change in momentum

Newton's third law of motion

According to this law, to every action, there is always an equal and opposite reaction.

Law of conservation of linear momentum

It states that when no external force acts on a system, total linear momentum of the system remains constant.

- The law of conservation of momentum is one of the most fundamental law of mechanics.
- Recoil velocity of a gun : $V = -mv/M$
  where m = mass of bullet, M = mass of the gun, v = velocity of the bullet.
  Negative sign shows that the gun recoils in a direction opposite to that of the bullet.
- Rocket propulsion is an example of variable mass.
- Newton's third law of motion and principle of conservation of linear momentum form the basis of rocket propulsion.
- Thrust on the rocket $F = -u\frac{dm}{dt}$.

  Negative sign shows that thrust on the rocket is in a direction opposite to the direction of escaped gases.
- Velocity of rocket $v = v_0 + u\ln\left(\frac{m_0}{m}\right)$

  where u = velocity of the ejected gases relative to the rocket, v_0 = initial velocity of the rocket, m_0 = initial mass of the rocket, dm/dt = rate of combustion of fuel at the instant t, m = mass of the rocket at time t.

Conservation of momentum

According to the principle of conservation of momentum, if there are no external forces acting on a system, the total momentum of the system remains constant.

i.e. if $F = 0$ then ΔP = constant

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Equilibrium of concurrent forces

A number of concurrent forces acting on a body are said to be in equilibrium, if the resultant of these forces is zero or if the concurrent forces can be represented completely by the sides of a closed polygon takes in the same order.

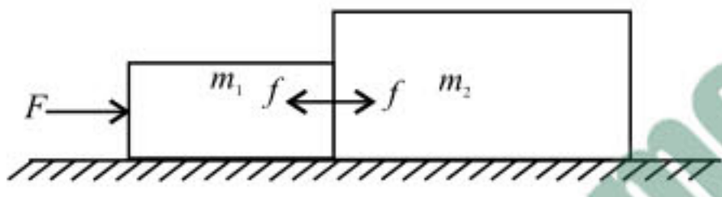
i.e., $\vec{F}_1 + \vec{F}_2 + \vec{F}_3 + ... + \vec{F}_n = 0$

Apparent weight of a man in a lift :

- When the lift is at rest or moving with constant velocity, the apparent weight = mg. Thus apparent weight = true weight.
- When the lift is accelerating upwards with acceleration a, then apparent weight = $m(g + a)$.
  Thus apparent weight is more than the true weight.
- When the lift is accelerating downwards with acceleration a, then apparent weight = $m(g - a)$.
  Thus apparent weight is less than the true weight.
- In the cable supporting the lift breaks, the lift falls freely with $a = g$, then apparent weight
  $= m(g - g) = 0$.

Motion of bodies in contact :

- When two bodies of masses m_1 and m_2 respectively are placed in contact with each other on a smooth horizontal surface. Let a force F is applied on m_1 as shown in the figure.



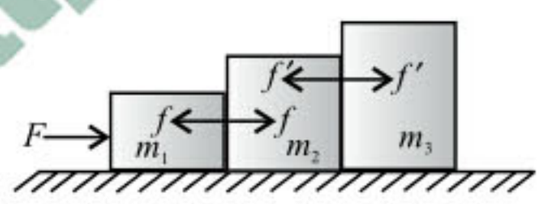
Common acceleration of the system,

$$a = \frac{F}{m_1 + m_2}$$

Contact force between m_1 and m_2,

$$f = \frac{m_2 F}{m_1 + m_2}$$

- When three bodies of masses m_1, m_2 and m_3 respectively are placed in contact with each other on a smooth horizontal surface. Let a force F is applied on m_1 as shown in the figure.



Common acceleration of the system,

$$a = \frac{F}{m_1 + m_2 + m_3}$$

Contact force between m_1 and m_2,

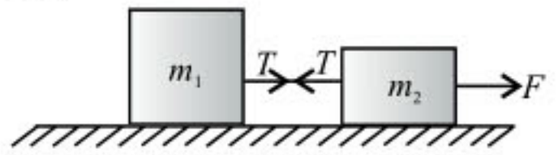
$$f = \frac{(m_2 + m_3)F}{m_1 + m_2 + m_3}$$

Contact force between m_2 and m_3,

$$f' = \frac{m_3 F}{m_1 + m_2 + m_3}$$

Motion of connected bodies :

- When two bodies of masses m_1 and m_2 respectively are connected by a uniform massless string and placed on a smooth horizontal surface. Let a force F is applied on m_2 as shown in the figure.

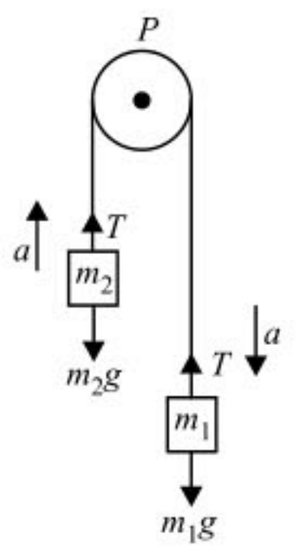


Common acceleration of the system,

$$a = \frac{F}{m_1 + m_2}$$

Tension, $T = \frac{m_1 F}{m_1 + m_2}$

- When two bodies of masses m_1 and m_2 ($m_1 > m_2$) connected by an inextensible string passing over a light frictionless pulley as shown in the figure



Acceleration of the system,

$$a = \frac{(m_1 - m_2)g}{m_1 + m_2}$$

Tension in the string,

$$T = \frac{2m_1 m_2 g}{m_1 + m_2}$$

Friction

The opposing force which comes into play when a body moves or tries to move over the surface of another body is known as frictional force or friction.

Types of friction

- Static friction : It is the opposing force which comes into existance when one object tends to move over the surface of other object, but the actual motion has yet not started.
  static friction, $f_s \le \mu_s F$
  where μ_s is the coefficient of static friction, and f is the normal force.
  Static friction is independent of the area of contact between the two surfaces.
- Limiting friction : It is the maximum value of static friction. Limiting friction is the maximum force which comes into existence when one body is just at the verge of moving over the surface of another object.
- Kinetic friction : It is the opposing force that comes into existance when one object is actually moving over the surface of the other object.
  kinetic friction, $f_k = \mu_k F$
  where μ_k is the coefficient of kinetic friction and F is the normal force
- Sliding friction : It is an opposing force that comes into play when one body is actually sliding over the surface of the other body.
- Rolling friction : It is an opposing force that comes into play when one body is actually rolling over the surface of the other body.

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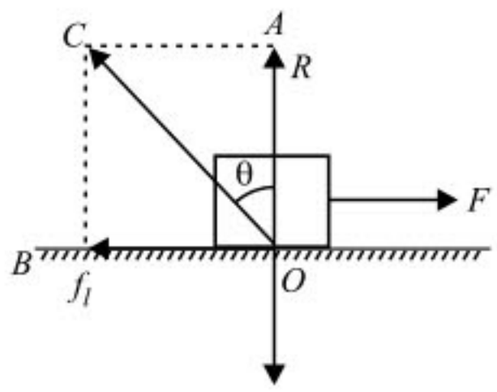
Angle of friction

It is defined as the angle which the resultant of normal reaction R and the force of limiting friction f_l makes with the direction of normal reaction (R).

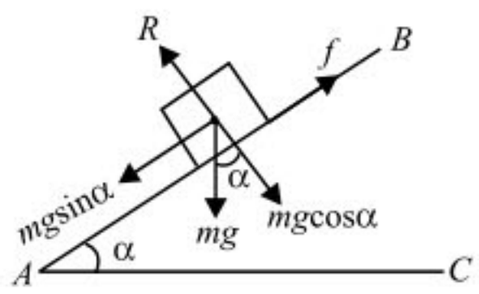


It is given as

$\tan\theta = \mu_s$ or $\theta = \tan^{-1}\mu_s$ ... (i)

Angle of repose

Angle of repose is defined as the minimum angle of inclination of a plane with the horizontal such that a body placed on the plane just begins to slide down.



It is given by

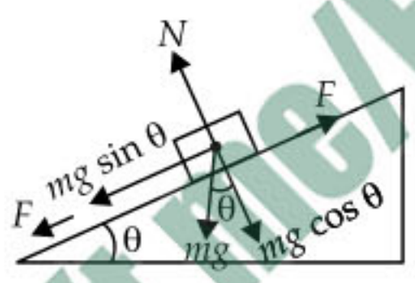
$\tan\alpha = \mu_s$ or $\alpha = \tan^{-1}\mu_s$ ... (ii)

From the equations (i) and (ii), it follows that $\theta = \alpha$.

i.e. angle of repose = angle of friction.

Acceleration of a body down a rough inclined plane

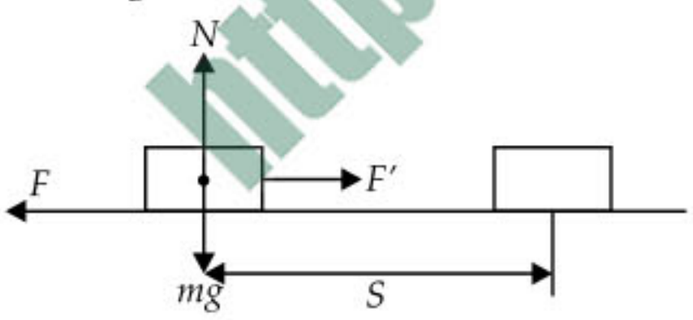
When a plane is inclined to the horizontal at an angle θ, which is greater than the angle of repose, the body placed on the inclined plane slides down with an acceleration a, then



$a = g(\sin\theta - \mu\cos\theta)$

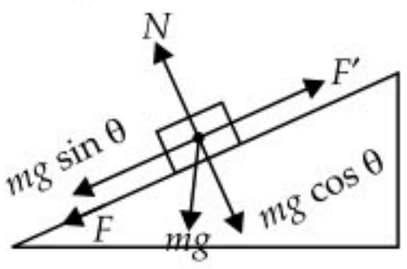
Work done in moving a body over a rough horizontal surface,

$W = \mu N \times S = \mu\, mg \times S$



Work done in moving a body up a rough inclined plane,

$W = mg(\sin\theta + \mu\cos\theta)S$



Advantages and disadvantages of friction

Some advantages of friction are as follows

- Friction help us to walk. Our foot pressing the ground for walking will slip, when there is no friction.
- For the working of breaks of the vehicles, friction is necessary.
- Writing on a paper or any surface will not be possible without friction.
- If there is no friction, two bodies will not stick to each other.

Some disadvantages of friction are as follows

- Friction causes wear and tear of the parts of machinery in contant.
- In machines, friction opposes relative motion with different moving parts and thereby dissipates power in the form of heat.
- Friction involves unnecessary expense of energy, that is why the output of machines are always less than input.

Methods to reduce friction

- Polishing makes the surfaces smoother, which help in reducing friction.
- Lubricants like oil, grease etc fill up the irregularities of the surfaces, making them smoother, reduces friction
- Friction can be reduced by proper selection of materials, as friction depends on nature of materials of the surfaces in contact.
- Friction due to air can be reduced by streamlining the shape of the body moving through air.
- By using ball bearings, between moving parts of a machine, friction can be reduced.

Dynamics of uniform circular motion

A uniform circular motion is the motion of an object travelling at a uniform speed on a circular path.

The force required to move a body uniformly in a circle is the centripetal force, which acts along the radius and towards the centre of the circle. The acceleration of a body undergoing circular motion is called the centripetal acceleration

$$a = \frac{v^2}{r} = r\omega^2$$

where v is linear velocity, ω is angular velocity and r is the radius of circular path.

Also, centripetal force F = mass × centripetal acceleration

$$= \frac{mv^2}{r} = mr\omega^2$$

Centripetal force

It is the force required to move a body uniformly in a circle. The centripetal force acts along the radius and towards the centre of the circle.

Magnitude of this force is $F = \frac{mv^2}{r} = mr\omega^2$

where v is the linear velocity, ω is angular velocity of the body and r is radius of the circular path.

Centrifugal force

It is a force that arises when a body is moving actually along a circular path, by virtue of tendency of the body to regain its natural straight line path.

Centrifugal force can be regarded as the reaction of centripetal force. The magnitude of centrifugal force is

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same as that of centripetal force. The direction of centrifugal force is opposite to the direction of centripetal force. The centrifugal force acts along the radius and away from the centre of the circle.

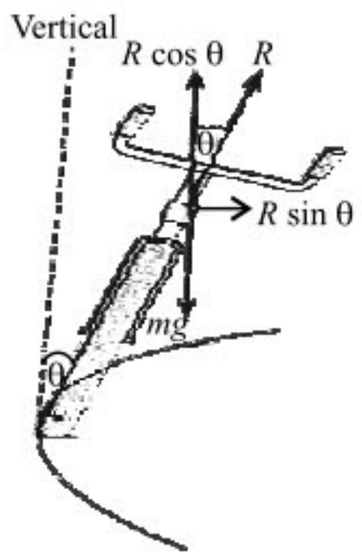
Examples of Circular Motion

Bending of cyclist

When a cyclist takes a turn, he also requires centripetal force. For this, he bends a little inwards from his vertical position, while turning. Angle θ of bending from vertical position is given by

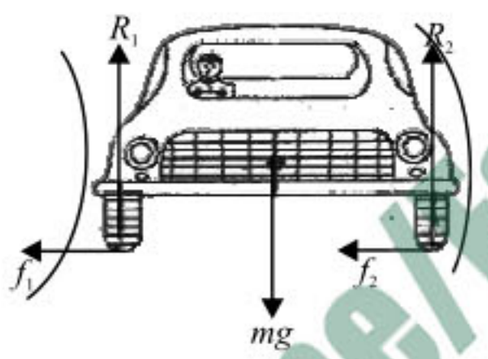
$$\tan\theta = \frac{v^2}{rg}$$

where, v = velocity of the cyclist while turning
r = radius of the circular path.



Motion of a car on a level road

When a car moves on a level horizontal circular road the force of friction between the tyre and the road provides the necessary centripetal force. The maximum velocity with which a car can take a circular path of radius r without slipping is given by

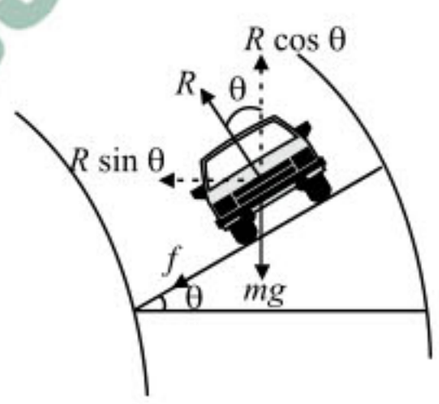


$$v_{max} = \sqrt{\mu_s rg}$$

where μ_s is the coefficient of friction between the tyres and the road.

Motion of a car on a banked circular road :

When a car moves on a flat horizontal circular road the force of friction between the tyre and the road provides the necessary centripetal force. This produces considerable wear and tear of the tyre.



To avoid this, an inclination is given to the road by raising the outer side of the road a little above the inner side. This is called banking of the road. The angle which the surface of the road makes with the horizontal is called the angle of banking.

- The maximum permissible speed to avoid slipping,

$$v_{max} = \left[\frac{rg(\mu_s + \tan\theta)}{1 - \mu_s \tan\theta}\right]^{1/2}$$

where μ_s is the coefficient of friction between the wheels of the car and the road and r is the radius of the circular road.

This speed v_{max} does not depend on the mass of the vehicle. *i.e.* it is same for all kinds of vehicles.

- If $\mu_s = 0$, *i.e.* if banked road is perfectly smooth, then

$$v_0 = \sqrt{rg\tan\theta}$$

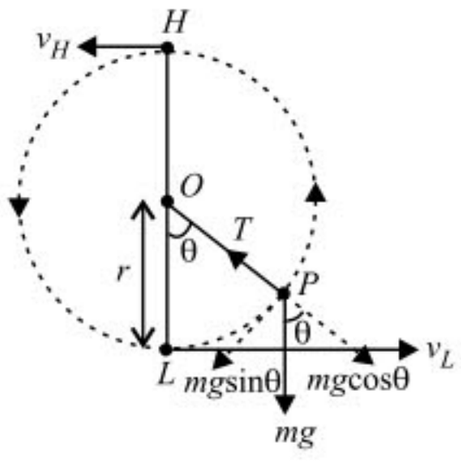
At this speed, frictional force is not needed to provide the necessary centripetal force. Driving at this speed on a banked road will cause almost no wear and tear of the tyres

- $v_0^2 = rg\tan\theta$ or $\tan\theta = \frac{v_0^2}{rg}$
- $\tan\theta = \frac{h}{\sqrt{b^2 - h^2}} = \frac{v_0^2}{rg}$

where b is breath of road ; h is height of outer edge above the inner edge and θ is the angle of banking.

Motion in a vertical circle:

When a small body of mass m is attached to an inextensible light string of length r and whirling in a vertical circle of radius r about a fixed point to which the other end of the string is attached as shown in figure.



- Tension at any position of angular displacement, (θ) along a vertical circle is given by $T = \frac{mv^2}{r} + mg\cos\theta$
- At the lowest point of vertical circle, θ = 0°
  Tension at the lowest point is given by

$$T_L = \frac{mv_L^2}{r} + mg$$

- At the highest point of the vertical circle, θ = 180°.
  Tension at the highest point is given by

$$T_H = \frac{mv_H^2}{r} - mg$$

- Minimum velocity at the highest point, $v_H = \sqrt{gr}$
- Minimum velocity at the lowest point for looping the loop, $v_L = \sqrt{5gr}$.
- When the string is horizontal, θ = 90°, minimum velocity, $v = \sqrt{3gr}$.
- Height through which a body should fall for looping the vertical loop $h = 5r/2$.

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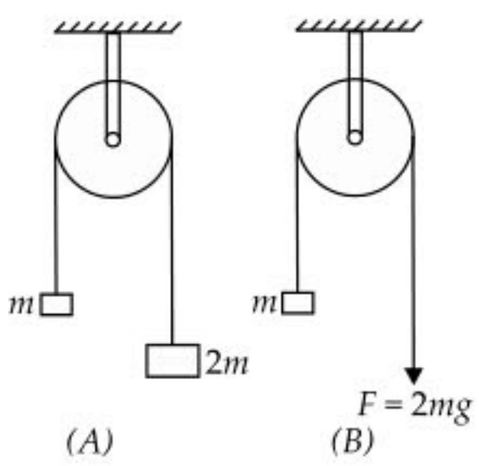
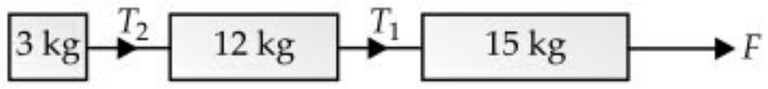
EXAM DRILL

1. Two pulley arrangements (A) and (B) are as shown in the figure. Neglect the masses of the ropes and pulleys and the friction at the axle of the pulleys. The ratio of the acceleration of mass m in arrangement (A) to that in arrangement (B) is



(a) 1 : 1 (b) 1 : 2 (c) 1 : 3 (d) 2 : 15

2. If the surfaces shown in figure are frictionless, the ratio of T_1 and T_2 is



(a) $\sqrt{3}:2$ (b) $1:\sqrt{3}$ (c) 1 : 5 (d) 5 : 1

3. Which one of the following statements is not true about Newton's second law of motion $\vec{F} = m\vec{a}$?

(a) The second law of motion is consistent with the first law.
(b) The second law of motion is a vector law.
(c) The second law of motion is applicable to a single point particle.
(d) The second law of motion is not a local law.

4. A body of mass 10 kg is acted upon by two perpendicular forces, 6 N and 8 N. The resultant acceleration of the body is

(a) 1 m s^{-2} at an angle of $\tan^{-1}\left(\frac{3}{4}\right)$ w.r.t. 8 N force.

(b) 0.2 m s^{-2} at an angle of $\tan^{-1}\left(\frac{3}{4}\right)$ w.r.t. 8 N force.

(c) 1 m s^{-2} at an angle of $\tan^{-1}\left(\frac{5}{4}\right)$ w.r.t. 8 N force.

(d) 0.2 m s^{-2} at an angle of $\tan^{-1}\left(\frac{5}{4}\right)$ w.r.t 8 N force.

5. A circular racetrack of radius 300 m is banked at an angle of 15°. If the coefficient of friction between the wheels of a race car and the road is 0.2, what is the maximum permissible speed to avoid slipping?
(Take $\tan 15° = 0.27$)

(a) 18.2 m s^{-1} (b) 28.2 m s^{-1}
(c) 38.2 m s^{-1} (d) 48.2 m s^{-1}

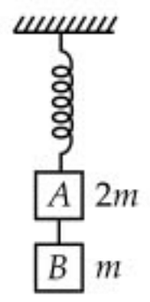
6. A hockey player is moving northward and suddenly turns westward with the same speed to avoid an opponent. The force that acts on the player is

(a) frictional force along westward.
(b) muscle force along southward.
(c) frictional force along south-west.
(d) muscle force along south-west.

7. A boy of mass 30 kg starts running from rest along a circular path of radius 6 m with constant tangential acceleration of magnitude 2 ms^{-2}. After 2 s from start he feels that his shoes started slipping on ground. The friction between his shoes and ground is
(Take $g = 10$ m s^{-2})

(a) $\frac{1}{2}$ (b) $\frac{1}{3}$ (c) $\frac{1}{4}$ (d) $\frac{1}{5}$

8. Two blocks A and B of masses $2m$ and m, respectively are connected by a massless and inextensible string. The whole system is suspended by a massless spring as shown in the figure. The magnitudes of acceleration A and B immediately after the string is cut, are respectively

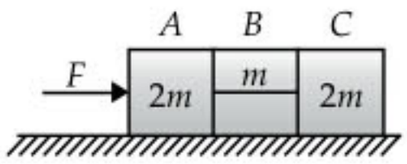


(a) $g, \frac{g}{2}$ (b) $\frac{g}{2}, g$ (c) g, g (d) $\frac{g}{2}, \frac{g}{2}$

9. A block of mass 10 kg is placed on rough horizontal surface whose coefficient of friction is 0.5. If a horizontal force of 100 N is applied on it, then acceleration of block will be [Take $g = 10$ m s^{-2}]

(a) 10 m s^{-2} (b) 5 m s^{-2}
(c) 15 m s^{-2} (d) 0.5 m s^{-2}

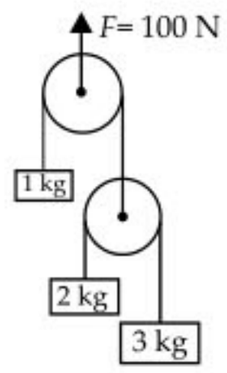
10. The system is pushed by a force F as shown in figure. All surfaces are smooth except between B and C. Friction coefficient between B and C is μ. Minimum value of F to prevent block B from downward slipping is



(a) $\left(\frac{3}{2\mu}\right)mg$ (b) $\left(\frac{5}{2\mu}\right)mg$

(c) $\left(\frac{5}{2}\right)\mu mg$ (d) $\left(\frac{3}{2}\right)\mu mg$

11. In the diagram shown in figure, both pulleys and strings are massless. The acceleration of 2 kg block is



(a) 2.5 m s^{-2} (↑)
(b) 5 m s^{-2} (↑)
(c) 7.5 m s^{-2} (↓)
(d) 10 m s^{-2} (↑)

12. An object is gently placed on a long conveyer belt moving with a speed of 5 m s^{-1}. If the coefficient of friction between the block and the belt is 0.5 the block will slide on the belt up to a distance
(Take $g = 10$ m s^{-2})

(a) 2.0 m (b) 2.5 m (c) 3.0 m (d) 3.5 m

13. A man of 50 kg mass is standing in a gravity free space at a height of 10 m above the floor. He throws a stone of 0.5 kg mass downwards with a speed 2 m s^{-1}. When the stone reaches the floor, the distance of the man above the floor will be

(a) 9.9 m (b) 10.1 m (c) 10 m (d) 20 m

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14. Two forces of equal magnitude F act at a point. If the angle between them is θ, then the magnitude of the resultant force is

(a) $F\sqrt{2(1-\sin\theta)}$ (b) $F\sqrt{2(1+\sin\theta)}$

(c) $2F\sin\frac{\theta}{2}$ (d) $2F\cos\left(\frac{\theta}{2}\right)$

15. A gramophone record is revolving with an angular velocity ω. A coin is placed at a distance r from the centre of the record. The static coefficient of friction is μ. The coin will revolve with the record if

(a) $r = \mu g\omega^2$ (b) $r < \frac{\omega^2}{\mu g}$

(c) $r \le \frac{\mu g}{\omega^2}$ (d) $r \ge \frac{\mu g}{\omega^2}$

16. A body of mass 2 kg travels according to the law $x(t) = pt + qt^2 + rt^3$ where $p = 3$ m s^{-1}, $q = 4$ m s^{-2} and $r = 5$ m s^{-3}. The force acting on the body at $t = 2$ s is

(a) 136 N (b) 134 N (c) 158 N (d) 68 N

17. A person of mass 50 kg stands on a weighing scale on a lift. If the lift is descending with a downward acceleration of 9 m s^{-2}, what would be the reading of the weighing scale? (Take $g = 10$ m s^{-2})

(a) 50 kg (b) 5 kg (c) 95 kg (d) 100 kg

18. Two billiard balls A and B, each of mass 50 g and moving in opposite directions with speed of 5 m s^{-1} each, collide and rebound with the same speed. The impulse imparted to each ball is

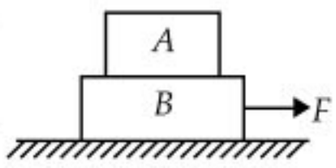
(a) 0.25 kg m s^{-1} (b) 0.5 kg m s^{-1}

(c) 0.1 kg m s^{-1} (d) 0.125 kg m s^{-1}

19. A body with mass 5 kg is acted upon by a force $\vec{F} = (-3\hat{i} + 4\hat{j})$ N. If its initial velocity at $t = 0$ is $\vec{u} = (6\hat{i} - 12\hat{j})$ m s^{-1}, the time at which it will just have a velocity along the y-axis is

(a) never (b) 10 s (c) 2 s (d) 15 s

20. In figure, the coefficient of friction between the floor and the block B is 0.1. The coefficient of friction between the blocks B and A is 0.2.

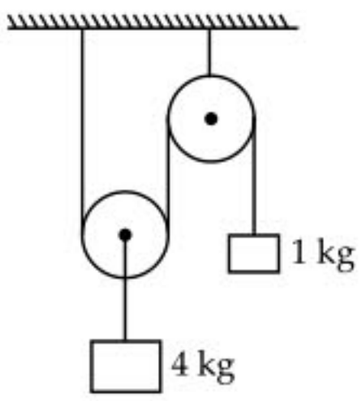


The mass of A is $m/2$ and of B is m. What is the maximum horizontal force F can be applied to the block B so that two blocks move together?

(a) $0.15mg$ (b) $0.05mg$

(c) $0.1mg$ (d) $0.45mg$

21. In the system shown in the adjoining figure, the acceleration of 1 kg mass is



(a) $\frac{g}{4}$ downwards

(b) $\frac{g}{2}$ downwards

(c) $\frac{g}{2}$ upwards

(d) $\frac{g}{4}$ upwards

22. Three blocks of masses m_1, m_2 and m_3 are placed in contact with each other on a frictionless table. A force F is applied on the heaviest mass m_1, the acceleration of m_3 will be

(a) $\frac{F}{m_1}$ (b) $\frac{F}{m_1 + m_2}$

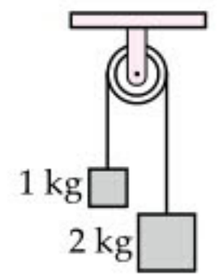
(c) $\frac{F}{m_2 + m_3}$ (d) $\frac{F}{m_1 + m_2 + m_3}$

23. A mass of 10 kg is suspended from a spring balance. It is pulled a side by a horizontal string so that it makes an angle of 60° with the vertical. The new reading of the balance is

(a) 20 kg wt (b) 10 kg wt

(c) $10\sqrt{3}$ kg wt (d) $20\sqrt{3}$ kg wt

24. Two unequal masses are connected on two sides of a light string passing over a light and smooth pulley as shown in figure. The system is released from rest. The larger mass is stopped for a moment, 1.0 s after the system is set into motion. The time elapsed before the string is tight again is



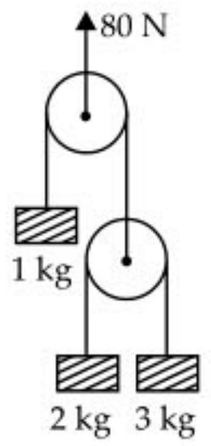
(Take $g = 10$ m s^{-2})

(a) $\frac{1}{4}$ s (b) $\frac{1}{2}$ s (c) $\frac{2}{3}$ s (d) $\frac{1}{3}$ s

25. The rear side of a truck is open and a box of mass 20 kg is placed on the truck 4 m away from the open end. The coefficient of friction between the box and the surface is 0.15. The truck starts from rest with an acceleration of 2 m s^{-2} on a straight road. The box will fall off the truck when it is at a distance from the starting point equal to

(a) 4 m (b) 8 m (c) 16 m (d) 32 m

26. The acceleration of 3 kg mass in figure shown is (Take $g = 10$ m s^{-2})



(a) $3\frac{1}{3}$ m s^{-2} upwards

(b) zero

(c) $16\frac{2}{3}$ m s^{-2} downwards

(d) $3\frac{1}{3}$ m s^{-2} downwards

27. A stream of water flowing horizontally with a speed of 15 m s^{-1} gushes out of a tube of cross-sectional area 10^{-2} m^2, and hits a vertical wall nearby. What is the force exerted on the wall by the impact of water, assuming it does not rebound?

(a) 1.25×10^3 N (b) 2.25×10^3 N

(c) 3.25×10^3 N (d) 4.25×10^3 N

28. Which one of the following statements is not true?

(a) The same force for the same time causes the same change in momentum for different bodies.

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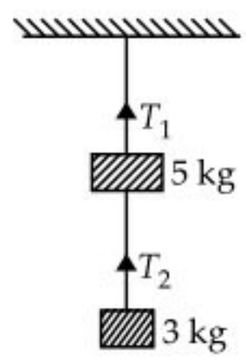
(b) The rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction in which the force acts.
(c) A greater opposing force is needed to stop a heavy body than a light body in the same time, if they are moving with the same speed.
(d) The greater the change in the momentum in a given time, the lesser is the force that needs to be applied.

29. A person in an elevator accelerating upwards with an acceleration of 2 m s^{-2}, tosses a coin vertically upwards with a speed of 20 m s^{-1}. After how much time will the coin fall back into his hand?
(Take $g = 10$ m s^{-2})
(a) 1.67 s (b) 2 s (c) 3.33 s (d) 5 s

30. Two masses of 5 kg and 3 kg are suspended with help of massless inextensible strings as shown in figure. The whole system is going upwards with an acceleration of 2 m s^{-2}. The tensions T_1 and T_2 are
(Take $g = 10$ m s^{-2})



(a) 96 N, 36 N (b) 36 N, 96 N
(c) 96 N, 96 N (d) 36 N, 36 N

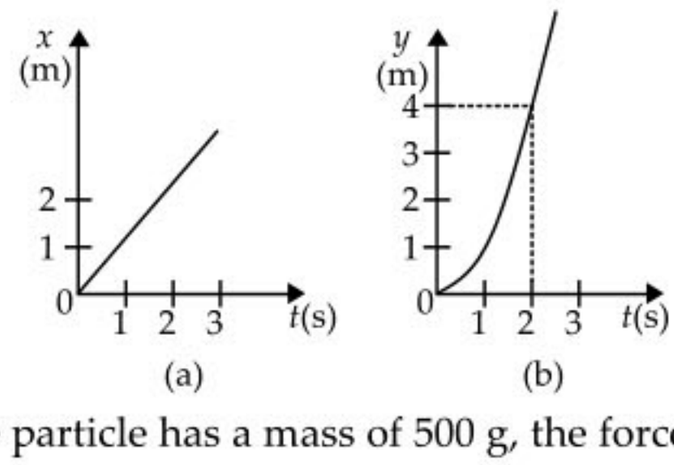
31. A block of mass M is held against a rough vertical wall by pressing it with a finger. If the coefficient of friction between the block and the wall is μ and the acceleration due to gravity is g, what is the minimum force required to be applied by the finger to hold the block against the wall?
(a) μMg (b) Mg (c) $\frac{Mg}{\mu}$ (d) $2\mu Mg$

32. A metre scale is moving with uniform velocity. This implies
(a) the force acting on the scale is zero, but a torque about the centre of mass can act on the scale.
(b) the force acting on the scale is zero and the torque acting about centre of mass of the scale is also zero.
(c) the total force acting on it need not be zero but the torque on it is zero.
(d) neither the force nor the torque need to be zero.

33. A 100 kg gun fires a ball of 1 kg horizontally from a cliff of height 500 m. It falls on the ground at a distance of 400 m from the bottom of the cliff. Find the recoil velocity of the gun.
(Take $g = 10$ m s^{-2})
(a) 0.2 m s^{-1} (b) 0.4 m s^{-1}
(c) 0.6 m s^{-1} (d) 0.8 m s^{-1}

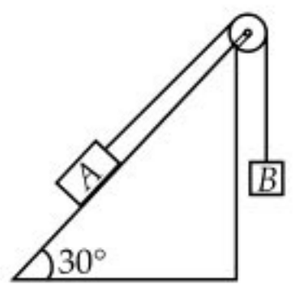
34. A large force is acting on a body for a short time. The impulse imparted is equal to the change in
(a) acceleration (b) momentum
(c) energy (d) velocity

35. Figure shows (x, t), (y, t) diagram of a particle moving in 2-dimensions.



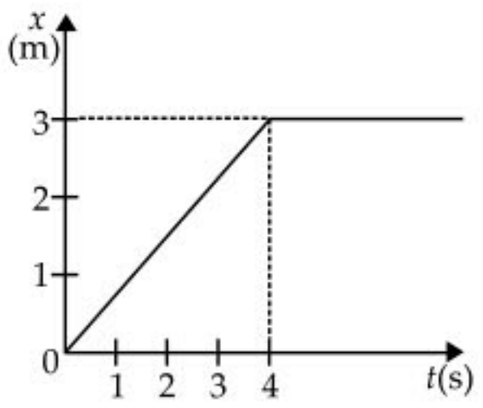
If the particle has a mass of 500 g, the force acting on the particle is
(a) 1 N along y-axis (b) 1 N along x-axis
(c) 0.5 N along x-axis (d) 0.5 N y-axis

36. Block A of weight 100 N rests on a frictionless inclined plane of slope angle 30° as shown in the figure. A flexible cord attached to A passes over a frictionless pulley and is connected to block B of weight W. Find the weight W for which the system is in equilibrium.



(a) 25 N (b) 50 N
(c) 75 N (d) 100 N

37. The position-time graph of a body of mass 2 kg is as given in figure. What is the impulse on the body at $t = 4$ s?



(a) $\frac{2}{3}$ kg m s^{-1}
(b) $-\frac{2}{3}$ kg m s^{-1}
(c) $\frac{3}{2}$ kg m s^{-1} (d) $-\frac{3}{2}$ kg m s^{-1}

38. One end of a string of length l is connected to a particle of mass m and the other to a small peg on a smooth horizontal table. If the particle moves in a circle with speed v the net force on the particle (directed towards the centre) is
(a) T (b) $T - \frac{mv^2}{l}$ (c) $T + \frac{mv^2}{l}$ (d) 0
Where T is the tension in the string.

39. Ten one-rupee coins are put on top of each other on a table. Each coin has a mass m. The force on the 7^{th} coin (counted from the bottom) due to all the coins on its top is
(a) $3mg$, vertically downwards
(b) $3mg$, vertically upwards
(c) $7mg$, vertically downwards
(d) $7mg$, vertically upwards

40. The net force acting on a drop of rain of mass 5 mg falling down with constant speed is
(a) 5 N (b) 5 mN
(c) zero (d) 5 dyne

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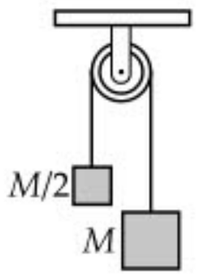
41. Two masses M and $M/2$ are joined together by means of light inextensible string passed over a frictionless pulley as shown in figure. When the bigger mass is released, the small one will ascend with an acceleration of

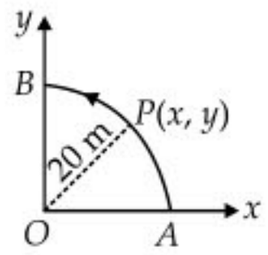


(a) $\frac{g}{3}$ (b) $\frac{3g}{2}$ (c) g (d) $\frac{g}{2}$

42. A car is moving on a circular level road of curvature 300 m. If the coefficient of friction is 0.3 and acceleration due to gravity is 10 m s^{-2}, the maximum speed of the car can be

(a) 90 km h^{-1} (b) 81 km h^{-1}
(c) 108 km h^{-1} (d) 162 km h^{-1}

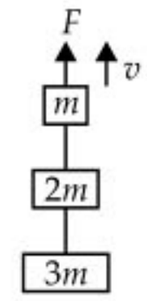
43. A point P moves in counter-clockwise direction on a circular path as shown in the figure. The movement of P is such that it sweeps out a length $s = t^3 + 5$; where s is in metres and t is in seconds.



The radius of the path is 20 m. The acceleration of P when $t = 2$ s is nearly

(a) 12 m s^{-2} (b) 7.2 m s^{-2}
(c) 14 m s^{-2} (d) 13 m s^{-2}

44. Three blocks with masses m, $2m$ and $3m$ are connected by strings, as shown in the figure. After an upward force F is applied on block m, the masses move upward at constant speed v. What is the net force on the block of mass $2m$?



(g is the acceleration due to gravity)

(a) $3mg$ (b) $6mg$
(c) zero (d) $2mg$

45. A monkey climbs up and another monkey climbs down a rope hanging from a tree with same uniform acceleration separately. If the respective masses of monkeys are in the ratio 2 : 3, the common acceleration must be

(a) $\frac{g}{5}$ (b) $6g$ (c) $\frac{g}{2}$ (d) g

DAY 04 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ◉

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____

(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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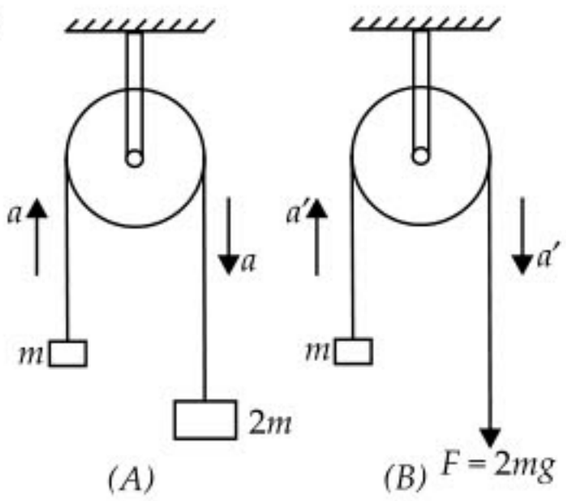
HINTS & SOLUTIONS

1. (c) :



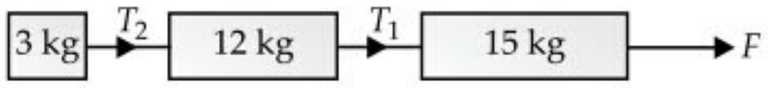
In case A, the acceleration of mass m is

$$a = \frac{(2m - m)g}{m + 2m} = \frac{g}{3}$$

In case B, the acceleration of mass m is

$$a' = \frac{2mg - mg}{m} = g \qquad \therefore \quad \frac{a}{a'} = \frac{1}{3}$$

2. (d) :



Acceleration of the system is

$$a = \frac{F}{3+12+15} = \frac{F}{30}\ \text{m s}^{-2}\ ;\ T_2 = 3a = 3 \times \frac{F}{30} = \frac{F}{10}$$

$$T_1 = (3+12)a = (3+12) \times \frac{F}{30} = \frac{F}{2}$$

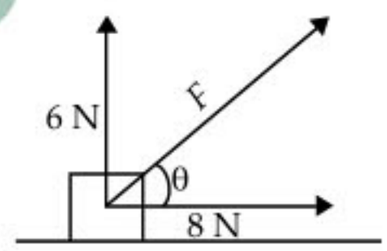
$$\therefore \quad \frac{T_1}{T_2} = \frac{5}{1} = 5:1$$

3. (d) : The second law of motion is a local law which means that force $\vec{F}$ at a point in space (location of the particle) at a certain instant of time is related to $\vec{a}$ at that point at that instant. Acceleration here and now is determined by the force here and now, not by any history of the motion of the particle.

4. (a) : Here, $m = 10$ kg

The resultant force acting on the body is

$$F = \sqrt{(8\ \text{N})^2 + (6\ \text{N})^2} = 10\ \text{N}$$



Let the resultant force F makes an θ w.r.t. 8 N force.

From figure, $\tan\theta = \dfrac{6\ \text{N}}{8\ \text{N}} = \dfrac{3}{4}$

The resultant acceleration of the body is

$$a = \frac{F}{m} = \frac{10\ \text{N}}{10\ \text{kg}} = 1\ \text{m s}^{-2}$$

The resultant acceleration is along the direction of the resultant force.

Hence, the resultant acceleration of the body is $1\ \text{m s}^{-2}$ at an angle of $\tan^{-1}\left(\dfrac{3}{4}\right)$ w.r.t. 8 N force.

5. (c) : Here $R = 300$ m, $\theta = 15°$, $g = 9.8\ \text{m s}^{-2}$, $\mu = 0.2$

The maximum permissible speed is given by

$$v_{\max} = \sqrt{\frac{Rg(\mu + \tan\theta)}{1 - \mu\tan\theta}} = \sqrt{\frac{300 \times 9.8 \times (0.2 + 0.27)}{1 - 0.2 \times 0.27}} = 38.2\ \text{m s}^{-1}$$

6. (c)

7. (b) : After 2 s speed of boy will be

$$v = 2 \times 2 = 4\ \text{m s}^{-1}$$

At this moment centripetal force on boy is

$$F_c = \frac{mv^2}{R} = \frac{30 \times 16}{6}\ \text{N} = 80\ \text{N}$$

Tangential force on boy is

$$F_t = ma = 30 \times 2\ \text{N} = 60\ \text{N}$$

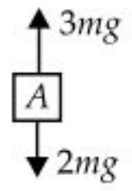
Total force acting on boy is

$$F = \sqrt{F_c^2 + F_t^2} = \sqrt{(80)^2 + (60)^2} = 100\ \text{N}$$

At the time of slipping, $F = \mu mg$

or $\quad 100 = \mu \times 30 \times 10$ or $\mu = \dfrac{1}{3}$

8. (b) : Just before the string is cut, force on the spring pulling up $= kx = 3mg$. After string is cut, free body diagram of block A gives



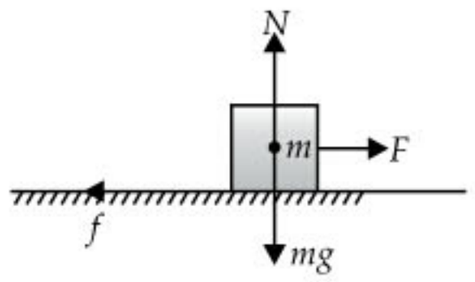
$$2ma_A = 3mg - 2mg$$

or $\quad a_A = \dfrac{mg}{2m} = \dfrac{g}{2}$

Free body diagram of block B gives

$ma_B = mg$ or $a_B = g$

9. (b) :



Here, $m = 10$ kg, $g = 10\ \text{m s}^{-2}$, $\mu = 0.5$, $F = 100$ N

Force of friction, $f = \mu N = \mu mg$

$$= 0.5 \times 10\ \text{kg} \times 10\ \text{m s}^{-2} = 50\ \text{N}$$

Force that produces acceleration

$$F' = F - f = 100\ \text{N} - 50\ \text{N} = 50\ \text{N}$$

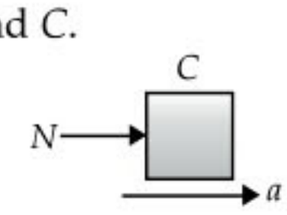
$$a = \frac{F'}{m} = \frac{50\ \text{N}}{10\ \text{kg}} = 5\ \text{m s}^{-2}$$

10. (b) : Horizontal acceleration of the system is

$$a = \frac{F}{2m + m + 2m} = \frac{F}{5m} \qquad \ldots(\text{i})$$

Let N be the normal reaction between B and C.

Free body diagram of C gives



$$N = 2ma = \frac{2}{5}F \ \text{(Using (i))}$$

Now B will not slide downward if

$$\mu N \geq \mu_B g$$

or $\quad \mu\left(\dfrac{2}{5}F\right) \geq mg$ or $F \geq \dfrac{5}{2\mu}mg$

So $\quad F_{\min} = \dfrac{5}{2\mu}mg$

11. (a) : From the equilibrium of pulley P_1 which is massless we can see that tension in upper string is is 50 N. Similarly, from equilibrium of P_2 we can see that tension in lower string will be 25 N.

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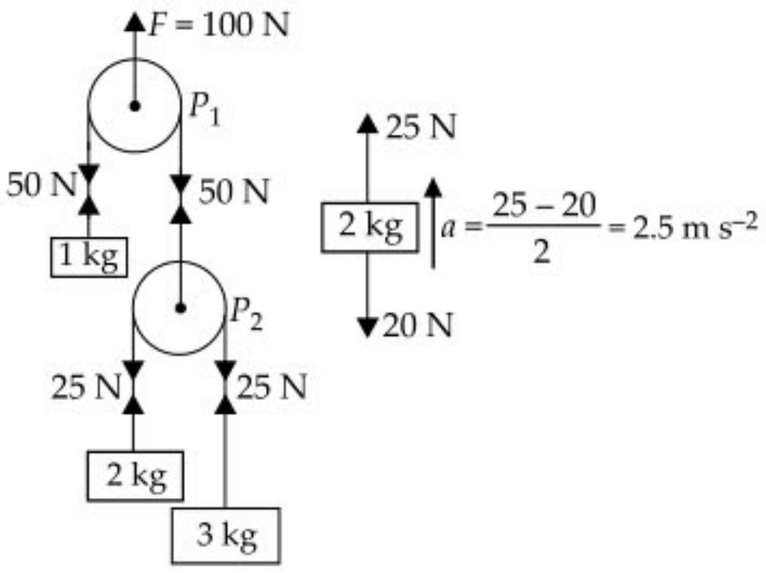


12. (b) : The force of friction between the block and the belt is $f = \mu mg$ where m is the mass of the object. This force produces an acceleration of the block which is given by

$$a = \frac{\text{force}}{\text{mass}} = \frac{\mu mg}{m} = \mu g$$

The block will slide on the belt without slipping until its speed (v) becomes equal to the speed of the belt. Since $u = 0$, we have $v^2 = 2as$

or $s = \dfrac{v^2}{2a} = \dfrac{v^2}{2\mu g} = \dfrac{(5\text{ m s}^{-1})^2}{2 \times 0.5 \times 10\text{ m s}^{-2}} = 2.5\text{ m}$

13. (b) : Here, $m_1 = 50$ kg, $m_2 = 0.5$ kg

$u_1 = ?$, $u_2 = 2\text{ m s}^{-1}$

According to law of convervation of linear momentum, we get, $m_1u_1 + m_2u_2 = 0$

$$u_1 = -\frac{m_2u_2}{m_1} = -\frac{0.5 \times 2}{50} = -\frac{1}{50}\text{ m s}^{-1}$$

Negative sign is for upward motion of man. In gravity free space, time taken by stone to reach the floor,

$$t = \frac{s}{u_2} = \frac{10}{2} = 5\text{ s}$$

Upward distance moved by the man $= \dfrac{1}{50} \times 5 = 0.1$ m

∴ Distance of man above the floor

$= (10 + 0.1)\text{ m} = 10.1\text{ m}$

14. (d) : Here, $F_1 = F_2 = F$

The magnitude of the resultant force is

$$F_R = \sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos\theta} = \sqrt{F^2 + F^2 + 2(F)(F)\cos\theta}$$

$$= \sqrt{2F^2 + 2F^2\cos\theta} = F\sqrt{2(1 + \cos\theta)}$$

$$= F\sqrt{2\left(2\cos^2\frac{\theta}{2}\right)} = 2F\cos\left(\frac{\theta}{2}\right)$$

15. (c) : The coin will revolve with the record, if Force of friction ≥ Centrifugal force

$$\mu mg \geq \mu r\omega^2 \text{ or } r \leq \frac{\mu g}{\omega^2}$$

16. (a) : Here, $x(t) = pt + qt^2 + rt^3$

where $p = 3\text{ m s}^{-1}$, $q = 4\text{ m s}^{-2}$ and $r = 5\text{ m s}^{-3}$

$m = 2$ kg

Velocity, $v = \dfrac{dx}{dt} = \dfrac{d}{dt}(pt + qt^2 + rt^3) = p + 2qt + 3rt^2$

Acceleration, $a = \dfrac{dv}{dt} = 2q + 6rt$

At $t = 2$ s

$a = 2(4\text{ m s}^{-2}) + 6(5\text{ m s}^{-3})(2\text{ s}) = 68\text{ m s}^{-2}$

The force acting on the body of mass 2 kg is

$F = ma = (2\text{ kg})(68\text{ m s}^{-2}) = 136$ N

17. (b) : The reading on the scale is a measure of the force on the floor by the person. By the Newton's third law this is equal and opposite to the normal force N on the person by the floor.

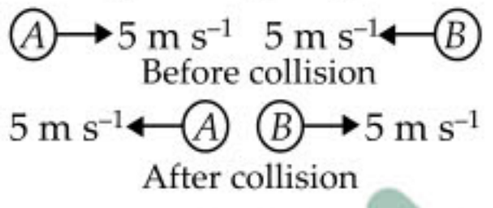
∴ When the lift is descending downward with a acceleration of $a\text{ m s}^{-2}$, then

$50 \times 10 - N = 50 \times 9$

or $N = 50 \times 10 - 50 \times 9 = 50$ N

∴ The reading of weighing machine is 5 kg.

18. (b) :



Initial momentum of ball $A = (0.05\text{ kg})(5\text{ m s}^{-1})$

$= 0.25\text{ kg m s}^{-1}$

As the speed is reversed on collision,

Final momentum of the ball A

$= (0.05\text{ kg})(-5\text{ m s}^{-1}) = -0.25\text{ kg m s}^{-1}$

Impulse imparted to the ball A

= Change in momentum of ball A

= Final momentum – Initial momentum

$= -0.25\text{ kg m s}^{-1} - 0.25\text{ kg m s}^{-1}$

$= -0.5\text{ kg m s}^{-1}$

Similarly,

Initial momentum of ball $B = (0.05\text{ kg})(-5\text{ m s}^{-1})$

$= -0.25\text{ kg m s}^{-1}$

Final momentum of ball $B = (0.05\text{ kg})(5\text{ m s}^{-1})$

$= +0.25\text{ kg m s}^{-1}$

Impulse imparted to ball B

$= (0.25\text{ kg m s}^{-1}) - (-0.25\text{ kg m s}^{-1})$

$= 0.5\text{ kg m s}^{-1}$

Impulse imparted to each ball is 0.5 kg m s^{-1} in magnitude. The two impulses are opposite in direction.

19. (b) : Here, $m = 5$ kg, $\vec{F} = -3\hat{i} + 4\hat{j}$ N

$\vec{u} = 6\hat{i} - 12\hat{j}\text{ m s}^{-1}$

The acceleration of the body is

$$\vec{a} = \frac{\vec{F}}{m} = \frac{(-3\hat{i} + 4\hat{j})\text{ N}}{5\text{ kg}} = -\frac{3}{5}\hat{i} + \frac{4}{5}\hat{j}\text{ m s}^{-2}$$

Velocity of the body along x-axis at any time t is

$$v_x = u_x + a_xt = 6\hat{i} - \frac{3}{5}\hat{i}t$$

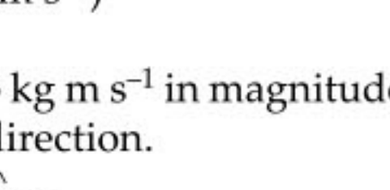
The body will have a velocity along y-axis, if its velocity along x-axis will be zero.

i.e. $v_x = 0 \Rightarrow t = 10$ s

20. (d) : Here, $m_A = \dfrac{m}{2}$, $m_B = m$

$\mu_A = 0.2$, $\mu_B = 0.1$

Let both the blocks are moving with common acceleration a. Then,



$$a = \frac{\mu_Am_Ag}{m_A} = \mu_Ag = 0.2g$$

and $F - \mu_B(m_B + m_A)g = (m_B + m_A)a$

$F = (m_B + m_A)a + \mu_B(m_B + m_A)g$

$$= \left(m + \frac{m}{2}\right)(0.2g) + (0.1)\left(m + \frac{m}{2}\right)g$$

$$= \left(\frac{3}{2}m\right)(0.2g) + \left(\frac{3}{2}m\right)(0.1g) = \frac{0.9}{2}mg = 0.45mg$$

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21. (c) : If a is downward acceleration of 4 kg block, the upward acceleration of 1 kg block must be $2a$.

If T is tension in each part of string, then equations of motion of the two blocks are

$4a = 4g - 2T$ ... (i)

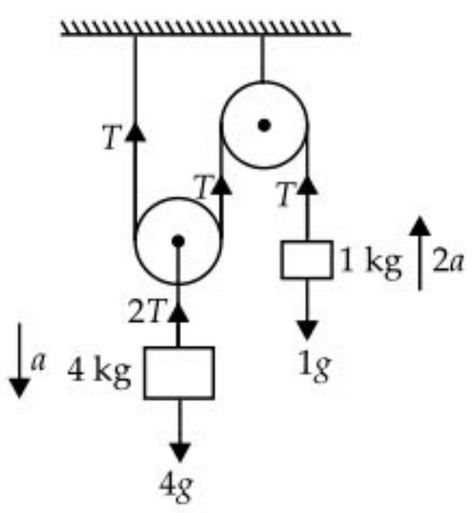
$1 \times 2a = T - 1g$ ...(ii)

or $4a = 2T - 2g$ ...(iii)

Adding (i) and (iii), we get

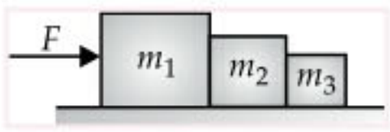
$$8a = 2g,\ a = \frac{g}{4}$$

$\therefore$ Acceleration of 1 kg block $= 2a = \frac{g}{2}$ upwards.



22. (d) : When three blocks of masses m_1, m_2 and m_3 are placed in contact with each other on a frictionless table and a force F is applied to them as shown in figure which produces a common acceleration a in them. It is given by

$$a = \frac{F}{m_1 + m_2 + m_3}$$



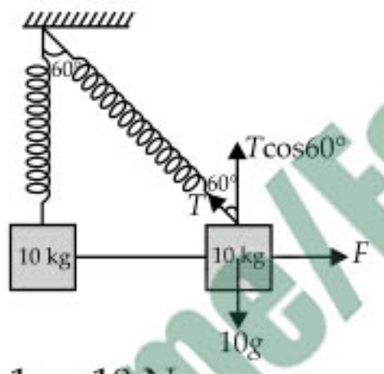
$\therefore$ The acceleration of mass m_3 is a.

23. (a) : The situation is shown in figure.

$T\cos\theta = 10g$

$$= \frac{10g}{\cos 60^\circ}$$

$= 20g = 20$ kg wt



24. (d) : Net pulling force $= 2g - 1g = 1g = 10$ N

Mass being pulled $= 2 + 1 = 3$ kg

$\therefore$ Acceleration of the system is $a = \frac{10}{3}$ m s^{-2}

$\therefore$ Velocity of both the blocks at $t = 1$ s will be

$$v = at = \left(\frac{10}{3}\text{ m s}^{-2}\right)(1\text{ s}) = \frac{10}{3}\text{ m s}^{-1}$$

Now, at this moment velocity of 2 kg block becomes zero, while that of 1 kg block is $\frac{10}{3}$ m s^{-1} upwards. Hence, string becomes tight again when,

Displacement of 1 kg block = Displacement of 2 kg block

or $vt - \frac{1}{2}gt^2 = \frac{1}{2}gt^2$ or $t = \frac{v}{g} = \frac{\frac{10}{3}\text{ m s}^{-1}}{10\text{ m s}^{-2}} = \frac{1}{3}$ s

25. (c) : Maximum acceleration of box $= \mu g$

$= 0.15 \times 10$ m s$^{-2} = 1.5$ m s^{-2}

Acceleration of truck, $a_T = 2$ m s^{-2}

Therefore, relative acceleration of the box, $a_r = 0.5$ m s^{-2} (backwards).

It will fall off the truck in a time,

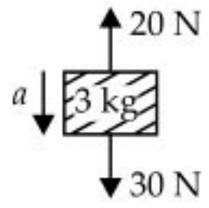
$$t = \sqrt{\frac{2S}{a_r}} = \sqrt{\frac{2\times 4}{0.5}} = 4\text{ s}$$

Displacement of truck upto the instant is,

$$S_T = \frac{1}{2}a_T t^2 = \frac{1}{2}\times 2\times (4)^2 = 16\text{ m}$$

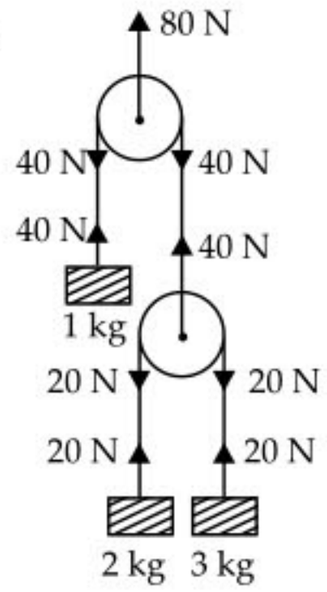
26. (d) : The tensions in all strings are as shown in the figure.

The free body diagram of 3 kg block is



$$a = \frac{30\text{ N} - 20\text{ N}}{3\text{ kg}} = \frac{10}{3}\text{ m s}^{-2}$$

$= 3\frac{1}{3}$ m s^{-2} downwards



27. (b) : Here, $v = 15$ m s^{-1}, $A = 10^{-2}$ m^2, $\rho = 10^3$ kg m^{-3}

Mass of water hitting the wall per second $= \rho \times A \times v$

$= 10^3$ kg m$^{-3} \times 10^{-2}$ m$^2 \times 15$ m s$^{-1} = 150$ kg s^{-1}

Force exerted on the wall

= Momentum loss of water per second

$= 150$ kg s$^{-1} \times 15$ m s$^{-1} = 2250$ N $= 2.25 \times 10^3$ N

28. (d) : The greater the change in the momentum in a given time, the greater is the force that needs to be applied.

29. (c) : Here, $v = 20$ m s^{-1}, $a = 2$ m s^{-2}, $g = 10$ m s^{-2}

The coin will fall back into the person's hand after t s.

$$\therefore\ t = \frac{2v}{a+g} = \frac{2\times 20\text{ m s}^{-1}}{(2+10)\text{ m s}^{-2}} = \frac{40}{12}\text{ s} = \frac{10}{3}\text{ s} = 3.33\text{ s}$$

30. (a) : The free body diagram of 3 kg block is as shown in the Fig. (a).

The equation of motion of 3 kg block is

$T_2 - 3g = 3a$

$T_2 = 3(a + g) = 3(2 + 10) = 36$ N ...(i)

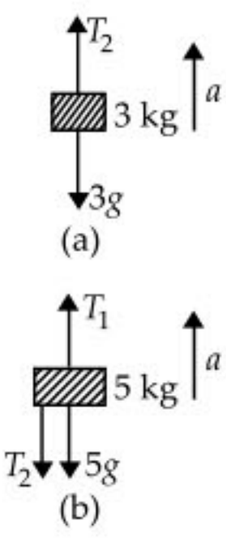
The free body diagram of 5 kg is as shown in the Fig. (b).

The equation of motion of 5 kg block is

$T_1 - T_2 - 5g = 5a$

$T_1 = 5(a + g) + T_2$

$= 5(2 + 10) + 36 = 96$ N (Using (i))



31. (c) : If F is the force of the finger on the book, $F = N$, the normal reaction of the wall on the book. The minimum upward frictional force needed to ensure that the book does not fall is Mg. The frictional force $= \mu N$.

Thus, minimum value of $F = \frac{Mg}{\mu}$.

32. (b)

33. (b) : Here, $M = 100$ kg, $m = 1$ kg, $h = 500$ m, $g = 10$ m s^{-2}

Time taken by the ball to reach the ground is

$$t = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2\times 500\text{ m}}{10\text{ m s}^{-2}}} = 10\text{ s}$$

Horizontal distance covered $= ut$

$\therefore\ 400 = u \times 10$

where u is the velocity of the ball.

$u = 40$ m s^{-1}

According to law of conservation of linear momentum, we get, $0 = Mv + mu$

$$v = -\frac{mu}{M} = -\frac{(1\text{ kg})(40\text{ m s}^{-1})}{100\text{ kg}} = -0.4\text{ m s}^{-1}$$

–ve sign shows that the direction of recoil of the gun is opposite to that of the ball.

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34. (b) : If a large force F acts for a short time dt the impulse imparted I is

$I = Fdt = \frac{dp}{dt}dt$

$I = dp$ = change in momentum

35. (a) : Since the graph between x and t is a straight line and passing through the origin.

$\therefore \quad x = t$

Since the graph between y and t is a parabola.

$\therefore \quad y = t^2$

$\therefore \quad v_x = \frac{dx}{dt} = 1$ and $a_x = \frac{dv_x}{dt} = 0$

and $v_y = \frac{dy}{dt} = 2t$ and $a_y = 2 \text{ m s}^{-2}$

The force acting on the particle is

$F = ma_y = (0.5 \text{ kg})(2 \text{ m s}^{-2})$

$= 1$ N along y-axis

36. (b) : As the system is in equilibrium,

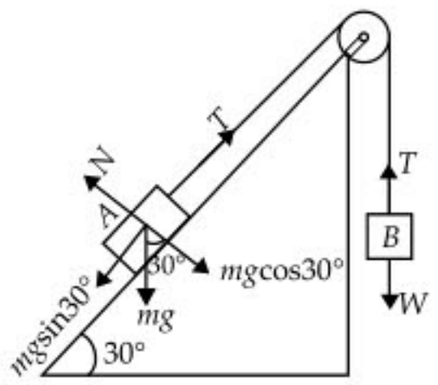
$\therefore \quad T = W \quad \ldots(i)$

and $T = mg\sin 30° \quad \ldots(ii)$

From (i) and (ii), we get

$W = mg\sin 30°$

$= (100 \text{ N})\frac{1}{2} = 50 \text{ N}$



37. (d) : At $t = 4$ s, the body has constant velocity

$u = \frac{3}{4} \text{ m s}^{-1}$.

After $t = 4$ s, the body is at rest *i.e.*, $v = 0$

$\therefore \quad$ Impulse $= m(v - u)$

$= 2 \text{ kg } (0 - \frac{3}{4} \text{ m s}^{-1}) = -\frac{3}{2} \text{ kg m s}^{-1}$

38. (a) : The net force on the particle is T and is directed towards the centre of the circle. The tension T provides the necessary centripetal force to the particle moving in the circle.

39. (a) : The force on 7th coin is due to weight of the three coins lying above it.

$\therefore \quad F = 3mg$

This force acts vertically downwards.

40. (c) : When a drop of rain of any mass falls down with constant speed, its acceleration, $a = 0$. Therefore, net force on the drop $F = ma = 0$.

41. (a) : Here, $m_1 = M$, $m_2 = M/2$

$$a = \frac{(m_1 - m_2)g}{m_1 + m_2} = \frac{\left(M - \frac{M}{2}\right)g}{M + \frac{M}{2}} = \frac{g}{3}$$

42. (c) : Here, $R = 300$ m, $\mu = 0.3$, $g = 10 \text{ m s}^{-2}$

The maximum speed of the car is

$v_{max} = \sqrt{\mu Rg} = \sqrt{0.3 \times 300 \text{ m} \times 10 \text{ m s}^{-2}}$

$= 30 \text{ m s}^{-1} = 30 \times \frac{18}{5} \text{ km h}^{-1} = 108 \text{ km h}^{-1}$

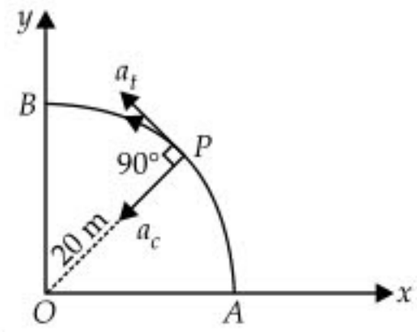
43. (c) : Here,

$s = t^3 + 5$; $r = 20$ m

Velocity, $v = \frac{ds}{dt} = 3t^2$

When, $t = 2$ s,

$v = 3 \times 2^2 = 12 \text{ m s}^{-1}$



Tangential acceleration, $a_t = \frac{dv}{dt} = 6t$

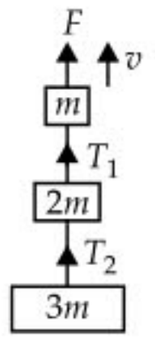
When, $t = 2$ s, $a_t = 6 \times 2 = 12 \text{ m s}^{-2}$

Centripetal acceleration, $a_c = \frac{v^2}{r} = \frac{12^2}{20} = 7.2 \text{ m s}^{-2}$

Effective acceleration, $a = \sqrt{a_t^2 + a_c^2} = \sqrt{12^2 + 7.2^2} = 14 \text{ m s}^{-2}$

44. (c) : Let T_1 be tension in string connecting m and $2m$ and T_2 be tension in string connecting $2m$ and $3m$.

Let a be common acceleration of the system.

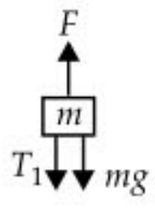


$\therefore \quad a = \frac{F - (m + 2m + 3m)g}{m + 2m + 3m} = \frac{F - 6mg}{6m}$

As the system moves with constant speed, therefore, $a = 0$

$\therefore \quad F - 6mg = 0$ or $F = 6mg$

The free body diagram of block m is as shown in the figure.



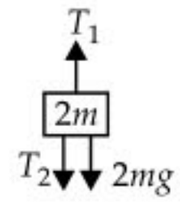
The equation of motion of block of mass m is

$F - T_1 - mg = 0$

$6mg - T_1 - mg = 0$

$T_1 = 5mg \quad \ldots(i)$

The free body diagram of block of mass $2m$ is as shown in the figure.



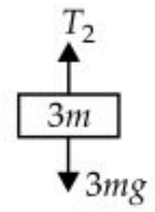
The equation of motion of block of mass $2m$ is

$T_1 - T_2 - 2mg = 0$

$5mg - T_2 - 2mg = 0 \quad$ (Using (i))

$T_2 = 3mg$

The free body diagram of block of mass $3m$ is as shown in the figure.



The equation of motion of block of mass $3m$ is

$T_2 - 3mg = 0$

$T_2 = 3mg$

Net force on the block of mass $2m$ is

$F_{net} = T_1 - T_2 - 2mg$

$= 5mg - 3mg - 2mg = 0$

45. (a) : Let T be the tension of a rope. When monkey climbs up with acceleration a,

$T - m_1 g = m_1 a \quad \ldots(i)$

When another monkey climbs down with same acceleration a, then

$m_2 g - T = m_2 a \quad \ldots(ii)$

Adding (i) and (ii), we get

$(m_2 - m_1)g = (m_1 + m_2)a$

or $\left(1 - \frac{m_1}{m_2}\right)g = \left(\frac{m_1}{m_2} + 1\right)a$ or $\left(1 - \frac{2}{3}\right)g = \left(\frac{2}{3} + 1\right)a$

$\frac{1}{3}g = \frac{5}{3}a$

or $a = \frac{g}{5}$

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Work, Energy and Power

Work

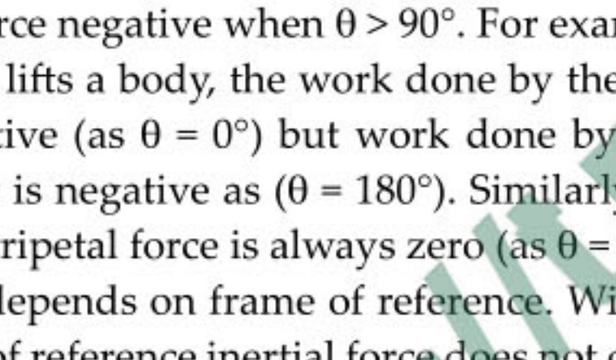
Work is said to be done by a force when the force produces a displacement in the body on which it acts in any direction except perpendicular to the direction of the force. Work is the product of the applied force and the displacement of the body in the direction of the force.

$$W = FS\cos\theta = \vec{F}\cdot\vec{S}$$

The SI unit of work is joule and CGS is erg.

1 joule = 10^7 erg

- **Nature of work** : Work can be positive, negative or even zero also, depending on the angle (θ) between the force vector $\vec{F}$ and displacement vector $\vec{S}$. Work done by a force negative when $\theta > 90°$. For example when a person lifts a body, the work done by the lifting force is positive (as $\theta = 0°$) but work done by the force of gravity is negative as ($\theta = 180°$). Similarly work done by centripetal force is always zero (as $\theta = 90°$).
  Work depends on frame of reference. With change of frame of reference inertial force does not change while displacement may change. So, the work done by a force will be different in different frames. For example, if a person is pushing a box inside a moving train, then work done as seen from the frame of reference of train is $\vec{F}\cdot\vec{S}$ while as seen from the ground it is $\vec{F}\cdot(\vec{S}+\vec{S}_o)$ here, $\vec{S}_o$ is the displacement of train relative to ground.
- **Work done by a variable force**



$$W = \int_{x_i}^{x_f} F(x)dx$$

W = area under the force-displacement graph.
Area under force-displacement curve must be added with proper sign to obtain work done by the force.

Conservative and non-conservative forces

- **Conservative force :** A force is said to be conservative if work done by the force in moving a body from one position to another position depends only on the initial and final positions of the body, and not on the nature of path followed between initial and the final positions. Alternatively, a force said to be conservative if work done by the force in moving a body in a closed path is zero.
  Gravitational force, electrostatic force and force in an elastic spring are the examples of the conservative forces. All central forces are conservative forces.
- **Non conservative force :** A force is said to be non-conservative if the work done by the force in moving a body from one position to another depend on the path followed between these two positions. Alternatively, a force is said to be non-conservative if work done by the force in moving a body in a closed loop is non zero.
  Frictional and viscous forces are the examples of non-conservative forces.

Energy

It is defined as the capacity of doing work.
Energy is a scalar quantity. Its dimensional formula and unit is same as that of work.
Some practical units of energy and their equivalence to joule are given in the table.

S.No.	Unit	Symbol	Equivalence in (J)
1.	1 erg	erg	10^{-7} J
2.	1 calorie	cal	4.2 J
3.	1 kilowatt hour	kWh	3.6×10^6 J
4.	1 electron volt	eV	1.6×10^{-19} J

Kinetic energy

It is defined as the energy possessed by the body by virtue of its motion. It is generally denoted by the letter K. Kinetic energy of a body of mass m moving with velocity v is given by

$$K = \frac{1}{2}mv^2$$

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- **Relation between kinetic energy (K) and linear momentum (p)**

$$K = \frac{p^2}{2m} \quad \text{or} \quad p = \sqrt{2mK}$$

This relation shows that a body cannot have kinetic energy without having momentum and vice-versa.
When linear momentum of a body increases by a factor n, its kinetic energy is increased by a factor n^2.
If the momenta of two bodies are equal then the kinetic energy of lighter body will be more.

$$p_1 = p_2 \quad \text{or} \quad \sqrt{2m_1K_1} = \sqrt{2m_2K_2}$$

$$\therefore \quad \frac{K_1}{K_2} = \frac{m_2}{m_1}$$

If the kinetic energy of two bodies are same then the momentum of heavier body will be more.

$$K_1 = K_2 \quad \text{or} \quad \frac{p_1^2}{2m_1} = \frac{p_2^2}{2m_2}$$

$$\therefore \quad \frac{p_1}{p_2} = \sqrt{\frac{m_1}{m_2}}$$

Potential energy

It is defined as the energy possessed by the body by virtue of its position or configuration. It is generally denoted by the letter U.

Types of potential energy

- **Elastic potential energy :** It is energy associated with state of compression or stretching of an elastic spring and is given by

$$U = \frac{1}{2}kx^2$$

where k is the force constant and x is the stretch or compression.

- **Gravitational potential energy :** It is the energy possessed by a body by virtue of its position above the surface of the earth. Gravitational potential energy of a body of mass m at a height h above the surface of the earth is

$$U = mgh$$

where the variation of g with height is ignored.
In general, if two bodies of masses m_1 and m_2 are separated by a distance r, then the gravitational potential energy is

$$U = -\frac{Gm_1m_2}{r}$$

Conservative force is the negative gradient of the corresponding potential energy.

$$\vec{F} = -\left(\hat{i}\frac{\partial U}{\partial x} + \hat{j}\frac{\partial U}{\partial y} + \hat{k}\frac{\partial U}{\partial z}\right) = -\vec{\nabla}U$$

where $\vec{\nabla} = \hat{i}\frac{\partial}{\partial x} + \hat{j}\frac{\partial}{\partial y} + \hat{k}\frac{\partial}{\partial z}$

In one dimension, $\vec{F} = -\frac{dU}{dx}$ or $U = -\int F dx$

- **Electric potential energy :** The electric potential energy of two point charges q_1 and q_2 separated by a distance r in vacuum is given by

$$U = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r}$$

Here, $\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$

Mechanical energy

It is defined as the sum of kinetic energy K and potential energy U.

i.e. $E = K + U$

- **Principle of conservation of mechanical energy :** It states that for conservative forces the sum of kinetic and potential energies at any point remains constant throughout the motion. It does not depend on time.
  i.e. $K_1 + U_1 = K_2 + U_2$ or $K + U =$ constant
- **Work energy theorem :** It states that work done by a force acting on a body is equal to change in kinetic energy of the body.
  $W = K_f - K_i$
  where K_i and K_f are initial and final kinetic energies of the body.

Power

It is defined as rate of doing work

Power = Rate of doing work

$$= \frac{\text{work done}}{\text{time taken}}$$

Instantaneous power $P = \frac{dW}{dt} = \vec{F} \cdot \frac{d\vec{r}}{dt} = \vec{F} \cdot \vec{v}$

where $\vec{v}$ is the instantaneous velocity when the force is $\vec{F}$.
Power is a scalar quantity. Its dimensional formula is $[ML^2T^{-3}]$.
In SI system the unit of power is watt. It is denoted by symbol W.

$1 \text{ W} = 1 \text{ J s}^{-1}$.

In CGS system, the unit of power is erg s^{-1}.

$1 \text{ W} = 10^7 \text{ erg s}^{-1}$.

Bigger units of power are

1 kilowatt = 1 kW = 10^3 W

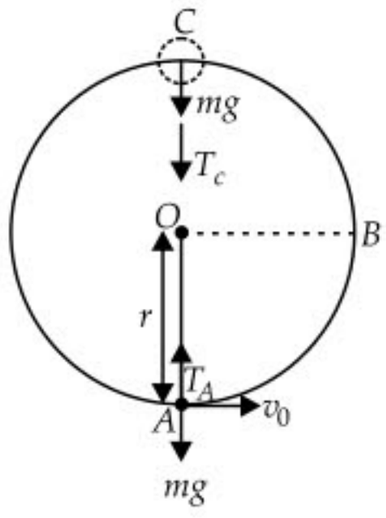
1 megawatt = 1 MW = 10^6 W

In engineering horse power is the practical unit of power.

1 hp = 746 W

Motion in vertical circle

When a small body of mass m is attached to an inextensible light string of length r and whirling in a vertical circle about a fixed point O to which the other end of the string is attached as shown in figure.
There are two external forces on the body : gravity and the tension (T) in the string.



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The latter does no work since the displacement of the body is always normal to the string. The potential energy of the bob is thus associated with the gravitational force only. The total mechanical energy E of the system is conserved. The potential energy of the system to be zero at the lowest point A. Thus, at A,

$$E = \frac{1}{2}mv_0^2 \qquad ...(i)$$

$$T_A - mg = \frac{mv_0^2}{r} \quad \text{(From Newton's second law)}$$

where, T_A is the tension in the string at A.

At the highest point C, the string slackens, at the tension in the string T_C becomes zero.

Thus at C,

$$E = \frac{1}{2}mv_C^2 + 2mgr \qquad ...(ii)$$

$$mg = \frac{mv_C^2}{r} \quad \text{(Newton's second law)} \quad ...(iii)$$

where v_c is the speed at C.

From (ii) and (iii)

$$E = \frac{5}{2}mgr$$

Equating this to the energy of A.

$$\frac{5}{2}mgr = \frac{m}{2}v_0^2 \text{ or } v_0 = \sqrt{5gr}$$

From equation (iii)

$$v_C = \sqrt{gr}$$

At B, the energy is

$$E = \frac{1}{2}mv_B^2 + mgr \qquad ...(iv)$$

From (i) and (iv), we get

$$\frac{1}{2}mv_B^2 + mgr = \frac{1}{2}mv_0^2$$

$$v_B = \sqrt{3gr} \quad (\text{Using } v_0 = \sqrt{5gr})$$

Collision

In physics a collision will take place if either of the two bodies come in physical contact with each other or even when path of one body is affected by the force exerted due to the other.

Collisions are broadly classified into two types :

Elastic collision

A collision in which both the momentum and kinetic energy of the body remains conserved. e.g. the collision between two billiard balls.

The basic characteristics of an elastic collision are :

- The momentum is conserved.
- Total energy is conserved.
- Kinetic energy is conserved.
- Forces involved in an elastic collision are of conservative nature.
- Mechanical energy is not transformed into any other form of energy.

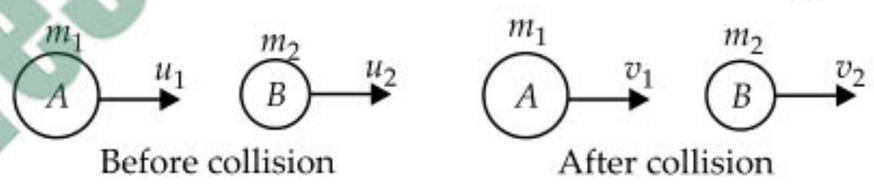
Inelastic collision

A collision in which only the momentum of the system is conserved but kinetic energy is not conserved. Most of the collisions in our day to day life are inelastic collisions. e.g. mud thrown on the wall.

The basic characteristics of an inelastic collision are

- Momentum is conserved.
- Total energy is conserved.
- Kinetic energy is not conserved.
- Some or all of the forces involved are non-conservative in nature.
- A part or whole of the mechanical energy may be transformed into other forms of energy.

Elastic collision in one dimension : Consider two bodies A and B of masses m_1 and m_2 moving along the same straight line with velocities u_1 and u_2 respectively. Assume that $u_1 > u_2$ so that two bodies collide. Let v_1 and v_2 be the final velocities of the bodies after collision. The two bodies suffer head on collision and continue moving along the straight line in the same direction as shown in the figure.



According to the law of conservation of momentum, we get

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

Since kinetic energy is conserved in elastic collision, we get

$$\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$$

$$v_1 = \frac{(m_1 - m_2)u_1}{(m_1 + m_2)} + \frac{2m_2u_2}{m_1 + m_2} \qquad ... (i)$$

$$v_2 = \frac{2m_1u_1}{m_1 + m_2} + \frac{(m_2 - m_1)}{m_1 + m_2}u_2 \qquad ... (ii)$$

Special cases

When masses of two bodies are equal,

$$i.e.\ m_1 = m_2 = m$$

From (i), we get $v_1 = u_2$

From (ii), we get $v_2 = \frac{2mu_1}{2m} = u_1$

Hence, when two bodies of equal masses undergo elastic collision in one dimension, then after the collision, the bodies will exchange their velocities.

When the body B is initially at rest *i.e.*, $u_2 = 0$.

From equation (i) and (ii), we get

$$v_1 = \frac{(m_1 - m_2)u_1}{m_1 + m_2} \qquad ... (iii)$$

$$v_2 = \frac{2m_1u_1}{m_1 + m_2} \qquad ... (iv)$$

Three cases arise further :

When masses of two bodies are equal *i.e.* $m_1 = m_2 = m$

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From (iii), we get $v_1 = 0$
From (iv), we get $v_2 = u_1$
Therefore, when body A collides with body B of equal mass at rest, the body A comes to rest while the body B moves on with the velocity of the body A.
In this case, transfer of kinetic energy is hundred percent.
When the body B has negligible mass as compared to that of body A *i.e.*, $m_2 << m_1$ then in equations (iii) and (iv), m_2 can be neglected as compared to m_1.

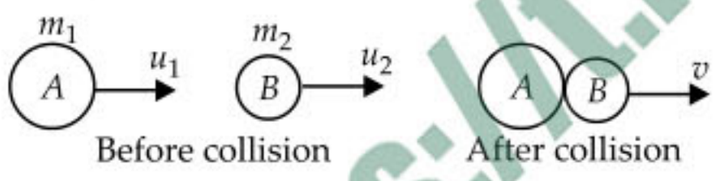
$$\therefore \quad v_1 = \frac{m_1 u_1}{m_1} = u_1 , \quad v_2 = \frac{2m_1 u_1}{m_1} = 2u_1$$

Therefore, when a heavy body A collides with a light body B at rest, the body A should keep on moving with same velocity and the body B starts moving with velocity double that of A.
When a mass of body B is very large as compared to that of body A *i.e.*, $m_2 >> m_1$ then in equations (iii) and (iv), m_1 can be neglected as compared to m_2.

$$v_1 = -\frac{m_2 u_1}{m_2} = -u_1 , \quad v_2 = 0$$

Therefore, when a light body A collides with a heavy body B at rest, the body A should start moving with same velocity just in opposite direction while the body B should practically remain at rest.

Perfectly inelastic collision in one dimension : Consider two bodies A and B of masses m_1 and m_2 moving with velocities u_1 and u_2 ($u_2 < u_1$) respectively along the same line collide head on and after collision they have same common velocity v.



According to conservation of linear momentum,

$$m_1 u_1 + m_2 u_2 = m_1 v + m_2 v$$

$$\text{or} \quad v = \frac{m_1 u_1 + m_2 u_2}{(m_1 + m_2)} \qquad \ldots \text{(i)}$$

Initial kinetic energy of the system is

$$K_i = \frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2$$

Final kinetic energy of the system is

$$K_f = \frac{1}{2}(m_1 + m_2) v^2$$

Loss in kinetic energy in inelastic collision is

$$\Delta K = K_i - K_f$$

$$= \left[\frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2\right] - \frac{1}{2}(m_1 + m_2) v^2 \qquad \ldots \text{(ii)}$$

Substituting the value of v from eqn. (i), we get

$$\Delta K = \frac{1}{2} \frac{m_1 m_2}{(m_1 + m_2)} (u_1 - u_2)^2$$

Coefficient of restitution : It is defined as the ratio of relative velocity of separation after collision to the relative velocity of approach before collision. It is represented by e.

$$e = \frac{\text{Relative velocity of separation (after collision)}}{\text{Relative velocity of collision (before collision)}}$$

$$e = \frac{v_2 - v_1}{u_1 - u_2}$$

where u_1, u_2 are velocities of two bodies before collision, and v_1, v_2 are their respective velocities after collision.
For perfectly elastic collision, $e = 1$.
For perfectly inelastic collision, $e = 0$.

General expressions for velocities after elastic collision are

$$v_1 = \frac{(m_1 - em_2)u_1}{m_1 + m_2} + \frac{(1+e)m_2 u_2}{m_1 + m_2}$$

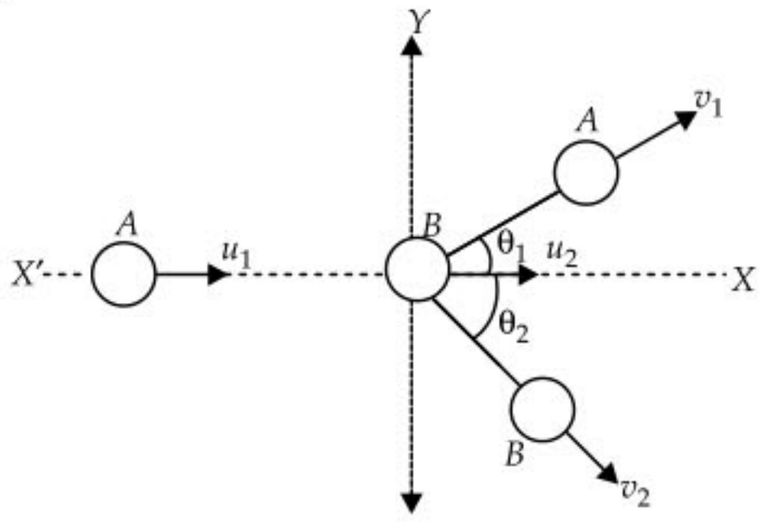
$$v_2 = \frac{(1+e)m_1 u_1}{m_1 + m_2} + \frac{(m_2 - em_1)u_2}{m_1 + m_2}$$

For a perfectly elastic collision, $e = 1$. These expressions reduce to the equations (i) and (ii).

Kinetic energy lost in inelastic collision is

$$\Delta K = \frac{1}{2} \frac{m_1 m_2}{(m_1 + m_2)} (u_1 - u_2)^2 (1 - e^2)$$

Elastic collision in two dimensions or oblique collision : Let us consider two bodies A and B of masses m_1 and m_2 moving along X-axis with velocities u_1 and u_2 respectively. When $u_1 > u_2$, the two bodies collide. After collision, body A moves with velocity v_1 at an angle θ_1 with X-axis and body B move with a velocity v_2 at an angle θ_2 with X-axis as shown in the figure.



Since the collision is elastic, kinetic energy is conserved.

$$\frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2 = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 \qquad \ldots \text{(i)}$$

Also momentum along X-axis before collision
= momentum after collision along X-axis

$$\Rightarrow \quad m_1 u_1 + m_2 u_2 = m_1 v_1 \cos\theta_1 + m_2 v_2 \cos\theta_2$$

Similarly along Y-axis

$$0 = m_1 v_1 \sin\theta_1 - m_2 v_2 \sin\theta_2 \qquad \ldots \text{(ii)}$$

Thus from these three equations (i), (ii) and (iii) we can find the required quantities.

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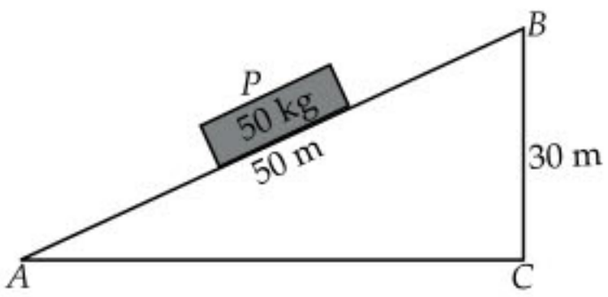
EXAM DRILL

1. A particle of mass m at rest is acted upon by a force P for time t. Its kinetic energy after time t is

(a) $\frac{P^2t^2}{m}$ (b) $\frac{P^2t^2}{2m}$ (c) $\frac{P^2t^2}{3m}$ (d) $\frac{Pt}{2m}$

2. In figure, a carriage P is pulled up from A to B. The relevant coefficient of friction is 0.40. The work done will be
(Take $g = 10\ \text{m s}^{-2}$)



(a) 10 kJ (b) 23 kJ
(c) 25 kJ (d) 28 kJ

3. A body of mass M is dropped from a height h on a sand floor. If the body penetrates x cm into the sand, the average resistance offered by the sand to the body is

(a) $Mg\left(\frac{h}{x}\right)$ (b) $Mg\left(1+\frac{h}{x}\right)$
(c) $Mgh + Mgx$ (d) $Mg\left(1-\frac{h}{x}\right)$

4. A man who is running has half the kinetic energy of a boy of half of his mass. The man has to speed up by $1\ \text{m s}^{-1}$ to have the same kinetic energy of the boy. What is the original speed of the boy?

(a) $\sqrt{2}\ \text{m s}^{-1}$ (b) $\left(\sqrt{2}-1\right)\text{m s}^{-1}$
(c) $2\ \text{m s}^{-1}$ (d) $2\left(\sqrt{2}+1\right)\text{m s}^{-1}$

5. A ball of mass m moving with a speed v makes a head on collision with an identical ball at rest. The kinetic energy after collision of the balls is three fourth of the original kinetic energy. The coefficient of restitution is

(a) $\frac{1}{2}$ (b) $\frac{1}{3}$ (c) $\frac{1}{\sqrt{2}}$ (d) $\frac{1}{\sqrt{3}}$

6. An electric motor of 100 W power drives a stirrer in a water bath. Only 80% of the energy supplied to the motor is used up in stirring water. The work done on water in 1 second is

(a) 100 J (b) 80 J
(c) 180 J (d) 145 J

7. Two spheres A and B of masses m_1 and m_2 respectively collide. A is at rest initially and B is moving with velocity v along x-axis. After collision B has a velocity $\frac{v}{2}$ in a direction perpendicular to the original direction. The mass A moves after collision in the direction

(a) same as that of B
(b) opposite to that of B
(c) $\theta = \tan^{-1}\left(\frac{1}{2}\right)$ to the x-axis
(d) $\theta = \tan^{-1}\left(-\frac{1}{2}\right)$ to the x-axis

8. A particle is projected at 60° to the horizontal with an energy E. The kinetic energy and potential energy at thehighest point are

(a) $\left(\frac{E}{2}, \frac{E}{2}\right)$ (b) $\left(\frac{3E}{4}, \frac{E}{4}\right)$
(c) $(E, 0)$ (d) $\left(\frac{E}{4}, \frac{3E}{4}\right)$

9. A particle is travelling along a straight line OX, The distance x (in metres) of the particle from O at a time t is given by $x = 37 + 27t - t^3$ where t is time in seconds. The distance of the particle from O when it comes to rest is

(a) 81 m (b) 91 m
(c) 101 m (d) 111 m

10. When a spring is stretched by 10 cm, the potential energy stored is E. When the spring is stretched by 10 cm more, the potential energy stored in the spring becomes

(a) $2E$ (b) $4E$
(c) $6E$ (d) $10E$

11. A spherical ball A of mass 4 kg, moving along a straight line strikes another spherical ball B of mass 1 kg at rest. After the collision, A and B move with velocities $v_1\ \text{m s}^{-1}$ and $v_2\ \text{m s}^{-1}$ respectively making angles of 30° and 60° with respect to the original direction of motion of A. The ratio $\frac{v_1}{v_2}$ will be

(a) $\frac{\sqrt{3}}{4}$ (b) $\frac{4}{\sqrt{3}}$
(c) $\frac{1}{\sqrt{3}}$ (d) $\sqrt{3}$

12. A girl in a swing is 2.5 m above ground at the maximum height and at 1.5 m above the ground at the lowest point. Her maximum velocity in the swing is ($g = 10\ \text{m s}^{-2}$)

(a) $5\sqrt{2}\ \text{m s}^{-1}$ (b) $2\sqrt{5}\ \text{m s}^{-1}$
(c) $2\sqrt{3}\ \text{m s}^{-1}$ (d) $3\sqrt{2}\ \text{m s}^{-1}$

13. A bomb of 12 kg explodes into two pieces of masses 4 kg and 8 kg. The velocity of 8 kg mass is $6\ \text{m s}^{-1}$. The kinetic energy of the other mass is

(a) 48 J (b) 32 J
(c) 24 J (d) 288 J

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14. A spring of spring constant 8 Ncm^{-1} has an extension of 5 cm. The minimum work done in joule in increasing the extension from 5 cm to 15 cm is
(a) 16 J (b) 8 J
(c) 4 J (d) 32 J

15. Two springs A and B are identical except that A is stiffer than B *i.e.*, $k_A > k_B$. If the two springs are stretched by the same force, then
(a) more work is done on B *i.e.*, $W_B > W_A$
(b) more work is done on A *i.e.*, $W_A > W_B$
(c) work done on A and B are equal
(d) work done depends upon the way in which they are stretched.

16. A body of mass 2 kg, initially at rest, is moved by 3 m along the horizontal by a force of 10 N acting at an angle of 60° with the horizontal. The kinetic energy gained by the body is
(a) 15 J (b) 20 J
(c) 25 J (d) 30 J

17. A man weighing 60 kg is standing on a trolley weighing 240 kg. The trolley is resting on frictionless horizontal rails. If the man starts walking on the trolley with a velocity of 1 m s^{-1}, then after 4 s, his displacement relative to the ground is
(a) 6 m (b) 4.8 m
(c) 3.2 m (d) 2.4 m

18. A body of mass 4 kg is moving with momentum of 8 kg m s^{-1}. A force 0.2 N acts on it in the direction of motion of the body for 10 s. The increase in kinetic energy in joule is
(a) 10 (b) 8.5
(c) 4.5 (d) 4

19. At certain point, the potential and kinetic energies of a body of mass 100 g projected vertically up are 3.6×10^7 erg and 6.2×10^7 erg respectively. The maximum height reached by the body and the velocity with which it is projected from the ground are
(a) 10 m, 14 m s^{-1} (b) 15 m, 19 m s^{-1}
(c) 10 m, 24 m s^{-1} (d) 20 m, 17 m s^{-1}

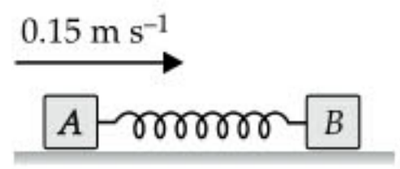
20. An open waterlight railway wagon of mass 5×10^3 kg is moving with an initial velocity of 1.2 m s^{-1} without friction on a railway track. Rain falls vertically downwards into the wagon. What change will occur in the kinetic energy of wagon, when it has collected 10^3 kg of water?
(a) 1200 J (b) 300 J
(c) 600 J (d) 900 J

21. The kinetic energy of a 800 gram stone is 100 J. Against a force of 50 N, how long will it travel ?
(a) 0.2 s (b) 0.1 s
(c) 0.3 s (d) 0.4 s

22. Two bodies of masses m_1 and m_2 are acted upon by a constant force F for a time t. They start from rest and acquire kinetic energies E_1 and E_2 respectively. Then $\frac{E_1}{E_2}$ is
(a) $\frac{m_1}{m_2}$ (b) $\frac{m_2}{m_1}$ (c) 1 (d) $\frac{\sqrt{m_1 m_2}}{m_1 + m_2}$

23. A uniform chain of length L and mass M is lying on a smooth table and one third of its length is hanging vertically down over the edge of the table. If g is acceleration due to gravity, work required to pull the hanging part on to the table is
(a) MgL (b) $\frac{MgL}{3}$ (c) $\frac{MgL}{9}$ (d) $\frac{MgL}{18}$

24. Two rectangular blocks A and B of masses 2 kg and 3 kg respectively are connected by a spring of spring constant 10.8 N m^{-1} and are placed on a frictionless horizontal surface. The block A was given an initial velocity of 0.15 m s^{-1} in the direction shown in the figure. The maximum compression of the spring during the motion is



(a) 0.01 m (b) 0.02 m
(c) 0.05 m (d) 0.03 m

25. A 4 kg mass and a 1 kg mass are moving with equal kinetic energies. The ratio of their momenta is
(a) 1 : 2 (b) 1 : 1
(c) 2 : 1 (d) 4 : 1

26. A ball moves on a frictionless inclined table without slipping. The work done by the table surface on the ball is
(a) positive (b) negative
(c) zero (d) none of these

27. What is the shape of the graph between the speed and kinetic energy of a body?
(a) Straight line (b) Hyperbola
(c) Parabola (d) Exponential

28. A bomb moving with velocity $(40\hat{i} + 50\hat{j} - 25\hat{k})$ m s^{-1} explode into two pieces of mass ratio 1 : 4. After explosion the smaller piece moves away with velocity $(200\hat{i} + 70\hat{j} + 15\hat{k})$ m s^{-1}. The velocity of larger piece after explosion is
(a) $45\hat{j} - 35\hat{k}$ (b) $45\hat{i} - 35\hat{j}$
(c) $45\hat{k} - 35\hat{j}$ (d) $-35\hat{i} + 45\hat{k}$

29. A body of mass 4 kg is moving with momentum of 8 kg m s^{-1}. A force of 0.2 N acts on it in the direction of motion of the body for 10 seconds. The increase in kinetic energy in joules is
(a) 10 (b) 8.5
(c) 4.5 (d) 4

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30. Consider the following statements *A* and *B*. Identify the correct choice in the given answers.
A. In a one dimensional perfectly elastic collision between two moving bodies of equal masses, the bodies merely exchange their velocities after collision.
B. If a lighter body at rest suffers perfectly elastic collision with a very heavy body moving with a certain velocity, then after collision both travel with same velocity.
(a) *A* and *B* are correct
(b) Both *A* and *B* are wrong
(c) *A* is correct, *B* is wrong
(d) *A* is wrong, *B* is correct

31. An engine pump is used to pump a liquid of density ρ continuously through a pipe of cross-sectional area *A*. If the speed of flow of the liquid in the pipe is v, then the rate at which kinetic energy is being imparted to the liquid is

(a) $\frac{1}{2}A\rho v^3$ (b) $\frac{1}{2}A\rho v^2$ (c) $\frac{1}{2}A\rho v$ (d) $A\rho v$

32. A body of mass 5 kg makes an elastic collision with another body at rest and continues to move in the original direction after collision with a velocity equal to $\left(\frac{1}{10}\right)^{th}$ of its original velocity. Then the mass of the second body is
(a) 4.09 kg (b) 0.5 kg
(c) 5 kg (d) 5.09 kg

33. Which of the following statements is incorrect?
(a) Kinetic energy may be zero, positive or negative.
(b) Potential energy may be zero, positive or negative.
(c) Power, energy and work are all scalars.
(d) Ballistic pendulum is a device for measuring the speed of bullets.

34. Water falls from a height of 60 m at the rate of 15 kg s^{-1} to operate a turbine. The losses due to frictional force are 10% of energy. How much power is generated by the turbine?
(Take $g = 10$ m s^{-2})
(a) 8.1 kW (b) 10.2 kW
(c) 12.3 kW (d) 7.0 kW

35. A body of mass m strikes another body at rest of mass $\frac{m}{9}$. Assuming the impact to be inelastic the fraction of the initial kinetic energy transformed into heat during the contact is
(a) 0.1 (b) 0.2
(c) 0.5 (d) 0.64

36. When a long spring is stretched by 2 cm, its potential energy is *U*. If the spring is stretched by 10 cm, the potential energy in it will be
(a) $10U$ (b) $25U$ (c) $\frac{U}{5}$ (d) $5U$

37. Which of the following is true for any collision?
(a) Both linear momentum and kinetic energy are conserved.
(b) Neither linear momentum nor kinetic energy may be conserved.
(c) Linear momentum is always conserved, however, kinetic energy may or may not be conserved.
(d) Kinetic energy is always conserved, but linear momentum may or may not be conserved.

38. A body of mass 10 kg initially at rest acquires velocity 10 m s^{-1}. What is the work done?
(a) –500 J (b) 500 J
(c) 50 J (d) –50 J

39. A 2 g ball of glass is released from the edge of a hemispherical cup whose radius is 20 cm. How much work is done on the ball by the gravitational force during the ball's motion to the bottom of the cup?

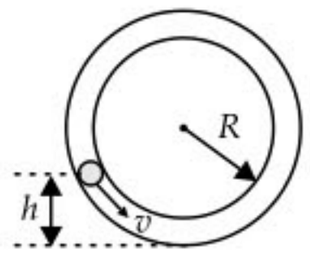
(a) 1.96 mJ (b) 3.92 mJ
(c) 4.90 mJ (d) 5.88 mJ

40. The momentum of a body is increased by 25%. The kinetic energy is increased by about
(a) 25% (b) 5%
(c) 56% (d) 38%

41. A body of mass 2 kg starts from rest and moves with uniform acceleration. It acquires a velocity 20 m s^{-1} in 4 s. The power exerted on the body in 2 s in watts is
(a) 50 (b) 100
(c) 150 (d) 200

42. One man takes 1 minute to raise a box to a height of 1 metre and another man takes $\frac{1}{2}$ minute to do so. The energy of the two is
(a) different
(b) same
(c) energy of the first is more
(d) energy of the second is more

43. With what minimum speed v must a small ball should be pushed inside a smooth vertical tube from a height h so that it may reach the top of the tube? Radius of the tube is *R*



(a) $\sqrt{2g(h+2R)}$ (b) $\frac{5}{2}R$
(c) $\sqrt{g(5R-2h)}$ (d) $\sqrt{2g(2R-h)}$

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44. At her maximum height, a girl in a swing is 3 m above the ground and at the lowest point, she is 2 m above the ground. What is her maximum velocity?

(a) $\sqrt{19.6}$ m s^{-1}
(b) $\sqrt{39.2}$ m s^{-1}
(c) $\sqrt{9.8}$ m s^{-1}
(d) 9.8 m s^{-1}

45. A block of mass 2 kg is initially at rest on a horizontal frictionless surface. A horizontal force $\vec{F} = (9 - x^2)\hat{i}$ N acts on it, when the block is at x = 0. The maximum kinetic energy of the block between x = 0 and x = 3 m in joule is

(a) 24 (b) 20
(c) 18 (d) 15

DAY 05 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____

(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (b) : $a = \frac{P}{m}, v = at = \frac{Pt}{m}$ $(\because \quad u = 0)$

Kinetic energy $= \frac{1}{2}mv^2 = \frac{1}{2}m\left[\frac{Pt}{m}\right]^2 = \frac{P^2t^2}{2m}$

2. (b) : Work done against gravity

$= 50 \times 10 \times \frac{30}{50} \times 50 \text{ J} = 15 \text{ kJ}$

Work done against friction

$= 0.4 \times 50 \times 10 \times \frac{40}{50} \times 50 \text{ J} = 8 \text{ kJ}$

Total work done = 15 kJ + 8 kJ = 23 kJ

3. (b) : If the body strikes the sand floor with a velocity v, then

Potential energy = Kinetic energy

$$Mgh = \frac{1}{2}Mv^2$$

With this velocity v, when body passes through the sand floor it comes to rest after travelling a distance x. Let F be the resisting force acting on the body. Net force in downward direction

$= Mg - F$

Work done by all the forces is equal to change in KE

$$(Mg - F)x = 0 - \frac{1}{2}Mv^2$$

$$(Mg - F)x = -Mgh$$

or $Fx = Mgh + Mgx$

or $F = Mg\left(1 + \frac{h}{x}\right)$

4. (d) : If M is the mass of man, $\frac{M}{2}$ is the mass of boy.

Let u be the velocity of the boy and his kinetic energy

$= \frac{1}{2}\frac{M}{2} \times u^2$

Kinetic energy of the man is $\frac{1}{2}Mv^2$ if v is his velocity.

According to problem,

$$\frac{1}{2}Mv^2 = \frac{1}{2}\left(\frac{1}{2}\frac{M}{2}u^2\right)$$

$$v^2 = \frac{u^2}{4} \quad \text{or} \quad v = \frac{u}{2}$$

New velocity of the man is $(v + 1)$. His kinetic energy now will be $\frac{1}{2}M(v+1)^2$. This is equal to $\frac{1}{2}\frac{M}{2}u^2$.

$$\therefore \quad \frac{1}{2}M(v+1)^2 = \frac{1}{2}\frac{M}{2}u^2$$

$$(v+1)^2 = \frac{u^2}{2}$$

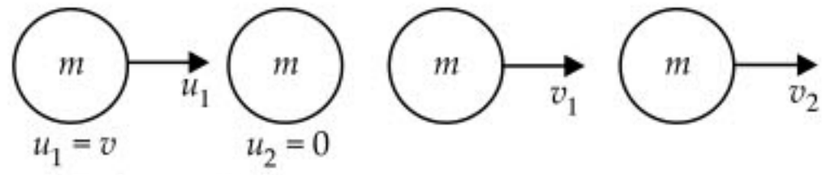
But $v = \frac{u}{2}$

$$\therefore \quad \left(\frac{u}{2}+1\right)^2 = \frac{u^2}{2} \quad \text{or} \quad \frac{\frac{u}{2}+1}{u} = \frac{1}{\sqrt{2}}$$

or $\frac{u}{\sqrt{2}} + \sqrt{2} = u$ or $u\left(1 - \frac{1}{\sqrt{2}}\right) = \sqrt{2}$

or $u\frac{(\sqrt{2}-1)}{\sqrt{2}} = \sqrt{2}$ or $u = \frac{2}{\sqrt{2}-1} = 2(\sqrt{2}+1)$

5. (c) :



Applying the principle of conservation of linear momentum, we get

$mv = mv_1 + mv_2$

$v = v_1 + v_2$ ...(i)

By definition of coefficient of restitution

$$e = \frac{v_2 - v_1}{u_1 - u_2} = \frac{v_2 - v_1}{v - 0}$$

or $v_2 - v_1 = ev$ ...(ii)

As K.E. after collision $= \frac{3}{4}$K.E. before collision

$$\therefore \quad \frac{1}{2}m\left(v_1^2 + v_2^2\right) = \frac{3}{4} \times \frac{1}{2}mv^2$$

$$v_1^2 + v_2^2 = \frac{3}{4}v^2 \quad \text{...(iii)}$$

Squaring (i), we get

$$v_1^2 + v_2^2 + 2v_1v_2 = v^2$$

Subtracting (iii), from this equation, we get

$$2v_1v_2 = \frac{1}{4}v^2 \quad \text{...(iv)}$$

Squaring (ii), we get

$$v_2^2 + v_1^2 - 2v_1v_2 = e^2v^2 \quad \text{...(v)}$$

Using (iii) and (iv) in (v), we get

$$\frac{3}{4}v^2 - \frac{1}{4}v^2 = e^2v^2$$

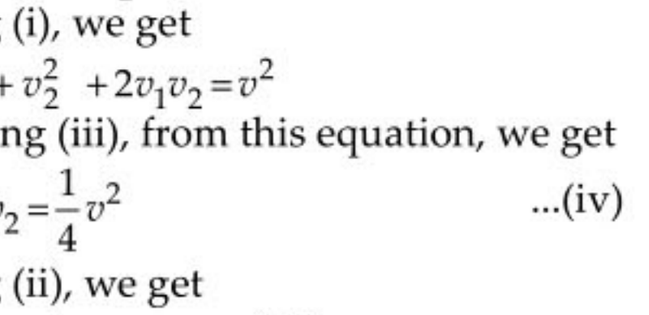
$$\frac{1}{2}v^2 = e^2v^2 \quad \text{or} \quad e = \frac{1}{\sqrt{2}}$$

6. (b) : Power consumed

$$= \frac{80}{100} \times 100 \text{ W} = 80 \text{ W} = 80 \text{ J s}^{-1}$$

So, work done in stirring water in one second is 80 J.

7. (d) :



According to law of conservation of linear momentum along x-axis, we get

$m_1 \times 0 + m_2 \times v = m_1v'\cos\theta$

$m_2v = m_1v'\cos\theta$

or $\cos\theta = \frac{m_2v}{m_1v'}$ ...(i)

According to law of conservation of linear momentum along y-axis, we get

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$$m_1 \times 0 + m_2 \times 0 = m_1 v' \sin\theta + m_2 \frac{v}{2}$$

$$-m_2 \frac{v}{2} = m_1 v' \sin\theta$$

$$\sin\theta = -\frac{m_2 v}{2 m_1 v'} \qquad ...(ii)$$

Divide (ii) by (i), we get

$$\tan\theta = -\frac{1}{2} \quad \text{or} \quad \theta = \tan^{-1}\left(-\frac{1}{2}\right) \text{ to the } x\text{-axis}$$

8. (d) : Initial KE, $E = \frac{1}{2}mu^2$ ...(i)

At the highest point, velocity $v = u\cos 60° = \frac{u}{2}$

KE at highest point $= \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{u}{2}\right)^2$

$$= \frac{1}{4}\left(\frac{1}{2}mu^2\right) = \frac{E}{4} \quad \text{(Using (i))}$$

PE at highest point $= mg \times \frac{u^2 \sin^2 60°}{2g}$

$$= \frac{1}{2}mu^2\left(\frac{\sqrt{3}}{2}\right)^2 = \frac{3}{4}E$$

9. (b) : Given : $x = 37 + 27t - t^3$

Velocity, $v = \frac{dx}{dt} = \frac{d}{dt}(37 + 27t - t^3)$

$$= 27 - 3t^2$$

It come to rest, $v = 0$

$\therefore \quad 27 - 3t^2 = 0$ or $3t^2 = 27$

or $t^2 = \frac{27}{3} = 9$ or $t = 3$ s

At $t = 3$ s,

$x = 37 + 27(3) - (3)^3 = 37 + 81 - 27 = 91$ m

10. (b) : Let k be spring constant of the spring.

Potential energy stored in the spring $= \frac{1}{2}kx^2$

In the first case,

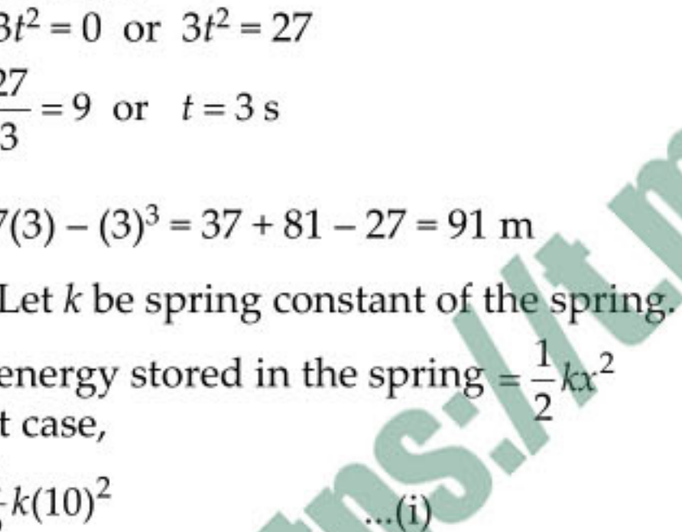
$$E = \frac{1}{2}k(10)^2 \qquad ...(i)$$

In the second case,

$$E' = \frac{1}{2}k(10+10)^2 = \frac{1}{2}k(20)^2$$

$$= 4\frac{1}{2}k(10)^2 = 4E \qquad \text{(Using(i))}$$

11. (a) :



Applying the law of conservation of linear momentum along a direction perpendicular to the direction of motion (*i.e.* along y-axis), we get

$$0 + 0 = 4v_1\sin 30° - v_2\sin 60°$$

$$4v_1\sin 30° = v_2\sin 60°$$

$$\frac{v_1}{v_2} = \frac{\sin 60°}{4\sin 30°} = \frac{\sqrt{3}}{4}$$

12. (b) : At the highest point, $v = 0$, $h_1 = 2.5$ m

$\therefore$ Total energy, $E_1 = mgh_1 + 0 = mgh_1$

At the lowest point, $v = ?$, $h_2 = 1.5$ m

$\therefore$ Total energy, $E_2 = mgh_2 + \frac{1}{2}mv^2$

According to the law of conservation of mechanical energy

$$E_1 = E_2$$

$$mgh_1 = \frac{1}{2}mv^2 + mgh_2$$

$$v^2 = 2g(h_1 - h_2)$$

$$v = \sqrt{2g(h_1 - h_2)} = \sqrt{2 \times 10 \times (2.5 - 1.5)}$$

$$= \sqrt{2 \times 10 \times 1} = \sqrt{20} \text{ m s}^{-1} = 2\sqrt{5} \text{ m s}^{-1}$$

13. (d) : According to law of conservation of linear momentum, $m_1v_1 + m_2v_2 = 0$

or $v_1 = -\frac{m_2 v_2}{m_1} = -\left(\frac{8 \times 6}{4}\right) = -12 \text{ m s}^{-1}$

$\therefore \quad \text{KE} = \frac{1}{2} \times m_1 v_1^2 = \frac{1}{2} \times 4 \times (12)^2 = 288$ J

14. (b) : Here, $k = 8 \text{ N cm}^{-1} = 8 \times 10^2 \text{ N m}^{-1}$

$x_1 = 5 \text{ cm} = 5 \times 10^{-2}$ m

$x_2 = 15 \text{ cm} = 15 \times 10^{-2}$ m

Work done = Increase in PE of spring

$$= \frac{1}{2}k(x_2^2 - x_1^2)$$

$$= \frac{1}{2} \times 8 \times 10^2 [(15 \times 10^{-2})^2 - (5 \times 10^{-2})^2]$$

$$= 4 \times 10^2 \times 200 \times 10^{-4} = 8 \text{ J}$$

15. (a) : $F = k_A x_A = k_B x_B$

or $\frac{x_A}{x_B} = \frac{k_B}{k_A}$ ...(i)

$$W_A = \frac{1}{2}k_A x_A^2; \; W_B = \frac{1}{2}k_B x_B^2$$

$$\frac{W_A}{W_B} = \frac{k_A}{k_B}\frac{x_A^2}{x_B^2} = \frac{k_A}{k_B}\frac{k_B^2}{k_A^2} = \frac{k_B}{k_A} \qquad \text{(Using (i))}$$

$\because \quad k_A > k_B$

Hence $W_B > W_A$. So more work is done on B.

16. (a) : Component of force along the direction of displacement $= F\cos\theta = 10 \times \cos 60° = 5$ N

Therefore, acceleration is

$$a = \frac{5 \text{ N}}{2 \text{ kg}} = 2.5 \text{ m s}^{-2}$$

As $v^2 - u^2 = 2as$

or $v^2 = 2as \qquad (\because u = 0)$

$\therefore \quad \text{KE} = \frac{1}{2}mv^2 = mas = 2 \times 2.5 \times 3 = 15$ J

17. (c) : The trolley shall move backwards to conserve momentum. The backward momentum would be shared by both the trolley and man.

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Applying conservation of momentum
$60 \times 1 = (240 + 60)v$ or $60 = 300v$

or $v = \frac{60}{300} = \frac{1}{5}\ \text{m s}^{-1} = 0.2\ \text{m s}^{-1}$

Speed of man w.r.t. ground $= (1 - 0.2)\ \text{m s}^{-1}$
$= 0.8\ \text{m s}^{-1}$

Displacement of man $= 0.8 \times 4 = 3.2$ m

18. (c) : Initially, $4u = 8 \Rightarrow u = 2\ \text{m s}^{-1}$

$mv - mu = Ft$

$mv - 8 = 0.2 \times 10$

or $v = \frac{10}{m} = \frac{10}{4} = \frac{5}{2}\ \text{m s}^{-1}$

Increase in $\text{KE} = \frac{1}{2}m(v^2 - u^2)$

$= \frac{1}{2} \times 4\left[\left(\frac{5}{2}\right)^2 - (2)^2\right]$

$= 4.5$ J

19. (a) : Total energy, $\text{TE} = \text{PE} + \text{KE} = 9.8 \times 10^7$ erg

At highest point : $\text{TE} = \text{PE} = mgh$

$9.8 \times 10^7 = mgh = 100 \times 980 \times h$

$h = 1000$ cm $= 10$ m

At lowest point : $\text{TE} = \text{KE} = \frac{1}{2}mv^2$

$9.8 \times 10^7 = \frac{1}{2} \times 100 \times v^2$

or $v^2 = 19.6 \times 10^5\ \text{cm}^2\ \text{s}^{-2}$

$\therefore\ v = 14\ \text{m s}^{-1}$

20. (c) : Initial momentum of the wagon
$= 5 \times 10^3 \times 1.2$

Let v' be the final velocity of the wagon.

Then final momentum of the wagon
$= (5 \times 10^3 + 10^3)v'$

According to law of conservation of momentum,
$(5 \times 10^3 + 10^3)v' = 5 \times 10^3 \times 1.2$

$\therefore\ v' = 1\ \text{m s}^{-1}$

Change in KE = Initial KE – Final KE

$= \frac{1}{2}(5 \times 10^3)(1.2)^2 - \frac{1}{2} \times (6 \times 10^3)(1)^2$

$= 3600 - 3000 = 600$ J

21. (a) : Here, $m = 500\ \text{g} = 0.5$ kg
KE = 100 J, $F = 50$ N

$a = -\frac{F}{m} = -\frac{50}{0.5} = -100\ \text{m s}^{-2}$

As $\frac{1}{2}mu^2 = \text{KE}$

$\therefore\ u = \sqrt{\frac{2\ \text{KE}}{m}} = \sqrt{\frac{2 \times 100}{0.5}} = 20\ \text{m s}^{-1}$

and $v = 0$

As $v = u + at$

$0 = 20 - 100t$ $(\because\ v = 0)$

$t = 0.2$ s

22. (b) : The acceleration of the body of mass m_1 acts upon by a constant F is

$$a_1 = \frac{F}{m_1} \qquad \text{...(i)}$$

The acceleration of the body of mass m_2 acts upon by a same constant F is

$$a_2 = \frac{F}{m_2} \qquad \text{...(ii)}$$

Starting from rest, the velocity acquired by mass m_1 in time t is

$$v_1 = a_1 t = \frac{F}{m_1}t \qquad \text{(Using (i))} \ \text{...(iii)}$$

Starting from rest, the velocity acquired by mass m_2 in the same time t is

$$v_2 = a_2 t = \frac{F}{m_2}t \qquad \text{(Using (ii))} \ \text{...(iv)}$$

Divide (iii) by (iv), we get

$$\therefore\ \frac{v_1}{v_2} = \frac{m_2}{m_1} \qquad \text{...(v)}$$

Kinetic energy of mass m_1 is

$$E_1 = \frac{1}{2}m_1 v_1^2 \qquad \text{...(vi)}$$

Kinetic energy of mass m_2 is

$$E_2 = \frac{1}{2}m_2 v_2^2 \qquad \text{...(vii)}$$

Divide (vi) by (vii), we get

$$\frac{E_1}{E_2} = \frac{m_1}{m_2}\left(\frac{v_1}{v_2}\right)^2$$

$$= \frac{m_1}{m_2}\left(\frac{m_2}{m_1}\right)^2 \qquad \text{(Using (v))}$$

$$= \frac{m_2}{m_1}$$

23. (d) : The weight of hanging part $\left(\frac{L}{3}\right)$ of chain is $\left(\frac{1}{3}Mg\right)$. This weight acts at centre of gravity of the hanging part, which is at a distance of $\left(\frac{L}{6}\right)$ from the table.

As work done = force × distance

$\therefore\ W = \frac{Mg}{3} \times \frac{L}{6} = \frac{MgL}{18}$

24. (c) : According to the law of conservation of linear momentum, we get

$m_A u = (m_A + m_B)v$

or $v = \frac{m_A u}{m_A + m_B} = \frac{(2\ \text{kg})(0.15\ \text{m s}^{-1})}{(2\ \text{kg} + 3\ \text{kg})} = 0.06\ \text{m s}^{-1}$

According to the law of conservation of energy, we get

$\frac{1}{2}m_A u^2 = \frac{1}{2}(m_A + m_B)v^2 + \frac{1}{2}kx^2$

$\frac{1}{2} \times 2 \times (0.15)^2 - \frac{1}{2}(2+3)(0.06)^2 = \frac{1}{2}kx^2$

or $0.027 = kx^2$

or $x = \sqrt{\frac{0.027}{k}} = \sqrt{\frac{0.027}{10.8}} = 0.05$ m

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25. (c) : As $K_1 = K_2 \quad \therefore \quad \frac{p_1^2}{2m_1} = \frac{p_2^2}{2m_2}$

or $\frac{p_1}{p_2} = \sqrt{\frac{m_1}{m_2}} = \sqrt{\frac{4}{1}} = 2:1$

26. (c) : Angle between normal reaction N and displacement S is 90°.

$\therefore \quad W = 0$

27. (c) : As kinetic energy $\propto v^2$, therefore graph between speed and kinetic energy must be parabolic.

28. (a) : Let the mass of the unexploded bomb be $5m$.
It explodes into the two pieces of masses m and $4m$ respectively.
Initial momentum of the unexploded bomb

$$= 5m(40\hat{i} + 50\hat{j} - 25\hat{k})$$

After explosion,
momentum of the smaller piece

$$= m\vec{v}_1 = m(200\hat{i} + 70\hat{j} + 15\hat{k})$$

and momentum of the larger piece $= 4m\vec{v}_2$

where $\vec{v}_1$ and $\vec{v}_2$ are the velocities of the two pieces respectively.
According to law of conservation of momentum, we get

$$5m(40\hat{i} + 50\hat{j} - 25\hat{k}) = m(200\hat{i} + 70\hat{j} + 15\hat{k}) + 4m\vec{v}_2$$

$$4m\vec{v}_2 = 5m(40\hat{i} + 50\hat{j} - 25\hat{k}) - m(200\hat{i} + 70\hat{j} + 15\hat{k})$$

$$\vec{v}_2 = \frac{1}{4}(180\hat{j} - 140\hat{k}) = 45\hat{j} - 35\hat{k}$$

29. (c) : Momentum = mass × velocity

$$p = mu$$

$$u = \frac{p}{m} = \frac{8 \text{ kg m s}^{-1}}{4 \text{ kg}} = 2 \text{ m s}^{-1}$$

$$\text{Acceleration} = \frac{\text{Force}}{\text{Mass}}$$

$$a = \frac{0.2 \text{ N}}{4 \text{ kg}} = 0.05 \text{ m s}^{-2}$$

Distance travelled by the body in 10 s is

$$S = ut + \frac{1}{2}at^2$$

$$= (2 \text{ m s}^{-1})(10 \text{ s}) + \frac{1}{2} \times (0.05 \text{ m s}^{-2})(10 \text{ s})^2$$

$$= 20 \text{ m} + 2.5 \text{ m} = 22.5 \text{ m}$$

Work done, $W = FS$

$$= (0.2 \text{ N})(22.5 \text{ m}) = 4.5 \text{ J}$$

According to work-energy theorem
Increase in kinetic energy = Work done

$$= 4.5 \text{ J}$$

30. (c) : For A:
Using the laws of conservation of linear momentum and energy, the velocities of two bodies after perfectly elastic collision are given by

$$v_1 = \frac{(m_1 - m_2)u_1}{m_1 + m_2} + \frac{2m_2u_2}{m_1 + m_2} \quad \ldots(\text{i})$$

$$v_2 = \frac{2m_1u_1}{m_1 + m_2} + \frac{(m_2 - m_1)u_2}{m_1 + m_2} \quad \ldots(\text{ii})$$

If $m_1 = m_2$, then
From (i) and (ii), we get

$$v_1 = u_2 \text{ and } v_2 = u_1$$

i.e., in perfectly elastic collision of two moving bodies of equal masses, the bodies merely exchange their velocities after collision. Thus, statement A is correct.
For B:
In eqs. (i) and (ii),
If $m_2 << m_1$ and $u_2 = 0$, then
$v_1 = u_1$ and $v_2 = 2u_1$
Thus, statement B is wrong.

31. (a) : Volume of liquid flowing per second = Av
Mass of liquid flowing per second, $m = Av\rho$
The rate at which kinetic energy is being imparted to the liquid is

$$= \frac{1}{2}mv^2 = \frac{1}{2}(Av\rho)v^2 = \frac{1}{2}A\rho v^3$$

32. (a) : Velocity of the first body after collision is given by

$$v_1 = \frac{(m_1 - m_2)u_1}{m_1 + m_2} + \frac{2m_2u_2}{m_1 + m_2}$$

Here, $m_1 = 5$ kg, $m_2 = ?$, $u_2 = 0$, $v_1 = \frac{u_1}{10}$

$$\therefore \quad \frac{u_1}{10} = \frac{(5 - m_2)}{5 + m_2}u_1 + 0$$

$$\frac{1}{10} = \frac{5 - m_2}{5 + m_2}$$

$$5 + m_2 = 50 - 10m_2$$

$$11m_2 = 45$$

$$m_2 = \frac{45}{11} = 4.09 \text{ kg}$$

33. (a) : Kinetic energy $= \frac{1}{2}mv^2$

Mass is always positive. v^2 is square of a vector quantity and is, therefore, positive. Thus, kinetic energy is always positive.

34. (a) : Power generated by the turbine is

$$P_{\text{generated}} = P_{\text{input}} \times \frac{90}{100}$$

$$= \frac{Mgh}{t} \times \frac{90}{100}$$

$$\therefore \quad P_{\text{generated}} = (15 \times 10 \times 60) \times \frac{90}{100}$$

$$= 8.1 \text{ kW}$$

35. (a) : Applying the law of conservation of linear momentum, we get

$$m \times u + \frac{m}{9} \times 0 = \left(m + \frac{m}{9}\right)v$$

$$v = \frac{u}{\left(\frac{10}{9}\right)}$$

$$v = \frac{9}{10}u$$

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Initial kinetic energy,

$$K_i = \frac{1}{2}mu^2$$

Final kinetic energy,

$$K_f = \frac{1}{2}\left(m + \frac{m}{9}\right)v^2 = \frac{1}{2}\left(\frac{10}{9}m\right)\left(\frac{9u}{10}\right)^2 = \frac{1}{2}\left(\frac{9}{10}\right)mu^2$$

Loss in kinetic energy, $\Delta K = K_i - K_f$

$$\Delta K = \frac{1}{2}mu^2 - \frac{1}{2}\left(\frac{9}{10}mu^2\right) = \frac{1}{2}\left(\frac{1}{10}\right)mu^2$$

Fraction of initial kinetic energy transformed into heat is

$$\frac{\text{Loss in kinetic energy}}{\text{Initial kinetic energy}} = \frac{\Delta K}{K_i} = \frac{\frac{1}{2}\left(\frac{1}{10}\right)mu^2}{\frac{1}{2}mu^2} = 0.1$$

36. (b) : Potential energy in a stretched spring is given by

$$U = \frac{1}{2}kx^2$$

$$\therefore \quad \frac{U_1}{U_2} = \left(\frac{x_1}{x_2}\right)^2 \quad \therefore \quad \frac{U_1}{U_2} = \left(\frac{0.02}{0.1}\right)^2 = \frac{1}{25}$$

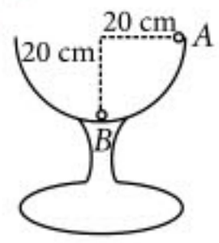
$$U_2 = 25U_1 = 25U$$

37. (c) : Linear momentum is conserved in all type of collisions but kinetic energy is not conserved in all type of collisions. Kinetic energy is conserved in elastic collisions but not conserved in inelastic collisions.

38. (b) : By work-energy theorem

$$W = \Delta K = \frac{1}{2} \times 10 \times (10)^2 - 0 = 500 \text{ J}$$

39. (b) : According to the conservation of energy,
kinetic energy at A + potential energy at A
= kinetic energy at B + potential energy at B



$$0 + mgh = \frac{1}{2}mv^2 + 0$$

or $\quad v^2 = 2gh = 2 \times 9.8 \times 0.20$

[$\because$ h = radius = 20 cm = 0.2 m]

According to work energy theorem work done on the ball
= change in kinetic energy

$$= \frac{1}{2} \times \frac{2}{1000} \times 2 \times 9.8 \times 0.2$$

$$= 3.92 \times 10^{-3} \text{ J} = 3.92 \text{ mJ}$$

40. (c) : Kinetic energy of the body is

$$K = \frac{p^2}{2m}$$

where p is the momentum and m is the mass of a body respectively.

$\therefore \quad K \propto p^2$

When the momentum of a body is increased by 25%, its momentum will become

$$p' = p + \frac{25}{100}p = \frac{125}{100}p = \frac{5}{4}p$$

$$\therefore \quad \frac{K'}{K} = \frac{p'^2}{p^2} = \left(\frac{5}{4}\right)^2 = \frac{25}{16} \quad \text{or} \quad K' = \frac{25}{16}K$$

Percentage increase in the kinetic energy of the body

$$= \frac{K' - K}{K} \times 100 = \frac{(25/16)K - K}{K} \times 100$$

$$= \frac{9}{16} \times 100 = 56\%$$

41. (b) : Let a body moves with uniform acceleration a. From $v = u + at$

Here, $u = 0$, $v = 20 \text{ m s}^{-1}$, $t = 4$ s

$$\therefore \quad a = \frac{v - u}{t} = \frac{20 - 0}{4} = 5 \text{ m s}^{-2}$$

Force exerted on the body,

$F = m \times a = (2 \text{ kg})\ (5 \text{ m s}^{-2}) = 10 \text{ N}$

Velocity acquired by the body in 2 s is

$v = (5 \text{ m s}^{-2})\ (2 \text{ s}) = 10 \text{ m s}^{-1}$

The power exerted on the body in 2 s is

$P = Fv = (10 \text{ N})\ (10 \text{ m}) = 100 \text{ W}$

42. (b) : Energy required = mgh. In both cases, h is the same. Hence, energy given by both is same. [It is worth noting here that powers of two men will be different as power is the energy expense per unit time and times are different here.]

43. (d) : Velocity of ball to just reach the top of the tube is given by

$$0 = v^2 - 2gh_0$$

Here, $\quad h_0 = (2R - h)$

and velocity will be zero at topmost point.

Thus $v = \sqrt{2g(2R - h)}$

44. (a) : At the highest point, $v = 0$, $h_1 = 3$ m

$\therefore$ Total energy, $E_1 = mgh_1 + 0$

At the lowest point, $v = ?$, $h_2 = 2$ m

Total energy, $E_2 = mgh_2 + \frac{1}{2}mv^2$

According to the law of conservation of energy,

$$E_2 = E_1$$

$$mgh_2 + \frac{1}{2}mv^2 = mgh_1$$

$$v = \sqrt{2g(h_2 - h_1)} = \sqrt{2 \times 9.8\,(3 - 2)}$$

$$v = \sqrt{19.6} \text{ m s}^{-1}$$

45. (c) : From work-energy theorem kinetic energy of the block at $x = x$ is

$$K = \int_0^x (9 - x^2)dx = \left[9x - \frac{x^3}{3}\right]$$

For K to be maximum, $\frac{dK}{dx} = 0$

or $\quad 9 - x^2 = 0 \quad$ or $\quad x = \pm 3$ m

At $x = +3$ m $\frac{d^2K}{dx^2}$ is negative

i.e., Kinetic energy K is maximum.

$$\therefore \quad K_{max} = 9(3) - \frac{(3)^3}{3} = 18 \text{ J}$$

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System of Particles and Rotational Motion

Centre of Mass

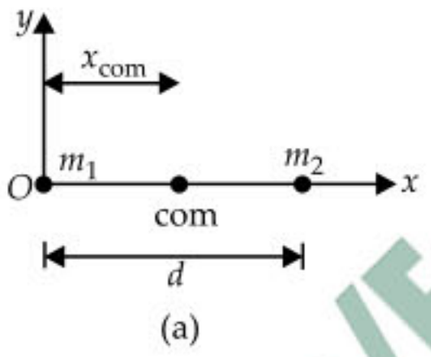
The centre of mass of a system of particles is the point that moves as though

(i) whole mass of the system is concentrated there and

(ii) all external forces applied there.

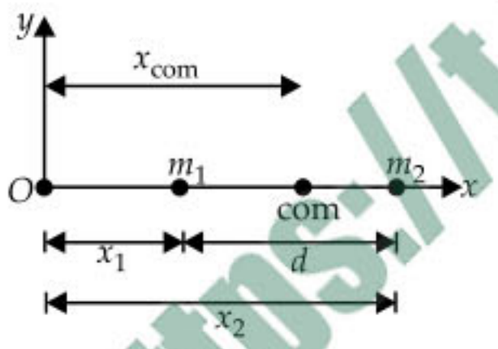
Centre of mass of a two particle system

In figure (a), two particles of masses m_1 and m_2 separated by distance d and the origin of an x axis to concide with the particle of mass m_1. The position of the centre of mass (com) of this two particles system is given by



(a)

$$x_{com} = \frac{m_2}{m_1 + m_2} d$$



(b)

In figure (b), in which the coordinate system has been shifted left ward. The position of the centre of mass is

$$x_{com} = \frac{m_1 x_1 + m_2 x_2}{m_1 + m_2}$$

Similarly for y and z-axis

$$y_{com} = \frac{m_1 y_1 + m_2 y_2}{m_1 + m_2} \text{ and } z_{com} = \frac{m_1 z_1 + m_2 z_2}{m_1 + m_2}$$

Centre of mass of n-particles system

For a system of n-particles of masses $m_1, m_2, m_3, ..., m_n$ having the position vectors $\vec{r}_1, \vec{r}_2, ..., \vec{r}_n$ respectively with respect to coordinate system.

Therefore, the position of the centre of mass of a system of n-particles is given by a position vector.

$$\vec{R}_{com} = \frac{m_1\vec{r}_1 + m_2\vec{r}_2 + ...m_n\vec{r}_n}{m_1 + m_2 + ... + m_n} = \frac{\sum_{i=1}^{n} m_i\vec{r}_i}{M}$$

Where, M is total mass of the system.

The coordinates of centres of mass are given by

$$x_{com} = \frac{\sum_{i=1}^{n} m_i x_i}{M}$$

$$y_{com} = \frac{\sum_{i=1}^{n} m_i y_i}{M}$$

$$z_{com} = \frac{\sum_{i=1}^{n} m_i z_i}{M}$$

Centre of mass of rigid body (or continuous distribution of mass)

The solid bodies contain so many particles (atoms) that we can treat as a continuous distribution of matter.

The 'particles' then become differential mass elements dm, the sum become integrals, and the coordinates of the centre of mass are defined as

$$x_{com} = \frac{1}{M}\int x dm$$

$$y_{com} = \frac{1}{M}\int y dm$$

$$z_{com} = \frac{1}{M}\int z dm$$

where M is the mass of the body.

The position of the centre of mass of a system is independent of the choice of coordinate system.

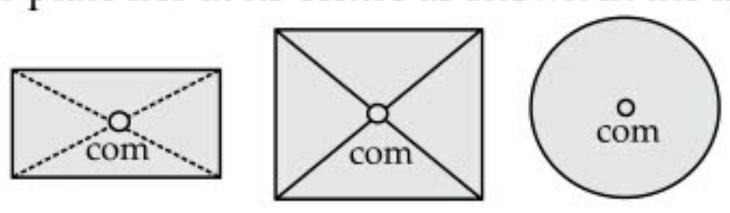
The position of the centre of mass depends on the shape of the body and the distribution of its mass. Hence it may lie within or outside the material of the body.

In symmetrical bodies in which the distribution of mass is homogeneous, the centre of mass coincides with the centre of symmetry or geometrical centre.

The centre of mass changes its position only under the translatory motion but remains unchanged in rotatory motion.

Centre of mass of some well known rigid bodies are given below :

- Centre of mass of a uniform rectangular, square or circular plate lies at its centre as shown in the figure.



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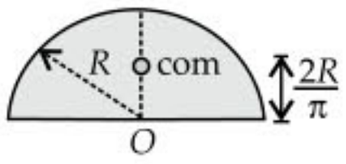
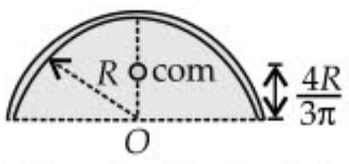
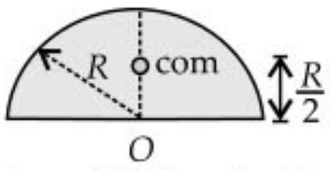
- Centre of mass of a uniform semicircular ring of radius R lies at a distance of $h = \frac{2R}{\pi}$ from its centre, on the axis of symmetry as shown in the figure



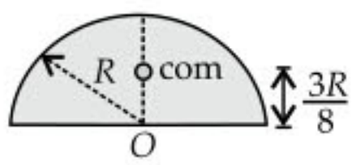
- Centre of mass of a uniform semicircular disc of radius R lies at a distance of $h = \frac{4R}{3\pi}$ from the centre on the axis of symmetry as shown in figure.



- Centre of mass of a hemispherical shell of radius R lies at a distance of $h = \frac{R}{2}$ from its centre on the axis of symmetry as shown in figure.



- Centre of mass of a solid hemisphere of radius R lies at a distance of $h = \frac{3R}{8}$ from its centre on the axis of symmetry as shown in the figure



Velocity of the centre of mass of a system of particles

Velocity of centre of mass is given by

$$\vec{v}_{com} = \frac{m_1\vec{v}_1 + m_2\vec{v}_2 + ... + m_n\vec{v}_n}{m_1 + m_2 + ... + m_n}$$

$$= \frac{\sum_{i=1}^{n} m_i\vec{v}_i}{\sum_{i=1}^{n} m_i} = \frac{\sum_{i=1}^{n} m_i\vec{v}_i}{M}$$

Acceleration of the centre of mass of a system of particles

Acceleration of centre of mass is given by

$$\vec{a}_{com} = \frac{m_1\vec{a}_1 + m_2\vec{a}_2 + ... + m_n\vec{a}_n}{m_1 + m_2 + ... + m_n}$$

$$= \frac{\sum_{i=1}^{n} m_i\vec{a}_i}{\sum_{i=1}^{n} m_i} = \frac{\sum_{i=1}^{n} m_i\vec{a}_i}{M}$$

If total external force acting on the system is zero, then the total linear momentum of the system is conserved. Also, when the total external force acting on the system is zero, the velocity of centre of mass remains constant.

Torque

Torque is the turning or twisting action on a body, about the axis of rotation due to a force.

If a force $\vec{F}$ is acting at any point in the body whose position vector relative to any arbitrary point on the axis of rotation is $\vec{r}$ then torque of the force an the body about the axis of rotation is given by

$$\vec{\tau} = \vec{r} \times \vec{F}$$

Also, $|\vec{\tau}| = rF\sin\theta$

where θ = angle between $\vec{r}$ and $\vec{F}$.

Torque is a vector quantity. Its SI unit is N m.

Torque has the same dimensions as that of work *i.e.* $[ML^2T^{-2}]$. But both are different. Work is a scalar quantity whereas torque is a vector quantity.

By sign convention, anticlockwise torque is taken as positive and clockwise torque is taken as negative.

Work done by Torque

Work done by torque $\vec{\tau}$,

$$W = \vec{\tau}\cdot\vec{\theta}$$

$\vec{\theta}$ = angular displacement.

For variable torque,

$$dW = \vec{\tau}\cdot d\vec{\theta}$$

Angular Momentum

Angular momentum of a particle about a given point is defined as

$$\vec{L} = \vec{r} \times \vec{p}$$

where, $\vec{r}$ = position vector of the particle with respect to the given point, $\vec{p}$ = linear momentum of the particle Direction of $\vec{L}$ can be determined by using the rule for vector product.

Angular momentum is a vector quantity. Its SI unit is kg m^2 s^{-1}. Its dimensional formula is $[ML^2T^{-1}]$.

Conservation of angular momentum

When there is no net external torque acting on a particle, then we can put $\frac{dL}{dt} = 0$

$$\vec{L} = \text{constant}$$

Therefore, the angular momentum of the particle remains unchanged in the absence of an external torque.

Relationship between torque and angular momentum

Rate of change of angular momentum of a body is equal to the external torque acting upon the body.

$$i.e.,\ \vec{\tau}_{ext} = \frac{d\vec{L}}{dt}$$

Equilibrium of rigid bodies

A rigid body is in mechanical equilibrium, if

- it is in translational equilibrium *i.e.* the total external force on it is zero. *i.e.* $\Sigma F_i = 0$.
- it is in rotational equilibrium, *i.e.*, the total external torque on it is zero, *i.e.* $\Sigma\tau_i = 0$.

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Kinematics Equations of Rotational Motion

The equations for uniform linear acceleration have rotational counterparts which are, by comparison,

$$\omega = \omega_0 + \alpha t \quad ...(i)$$

$$\theta = \omega_0 t + \frac{1}{2}\alpha t^2 \quad ...(ii)$$

$$\omega^2 = \omega_0^2 + 2\alpha\theta \quad ...(iii)$$

where ω_0 is the initial angular velocity and ω is the final angular velocity (both in rad s^{-1}) after the body has rotated through angular displacement θ (in rad) with constant angular acceleration α (in rad s^{-2}) in a time interval t (in s).

Analogy between translational motion and rotational motion

	Translational motion	Rotational motion
1.	Displacement s	Angular displacement θ
2.	Velocity $v = \frac{ds}{dt}$	Angular velocity $\omega = \frac{d\theta}{dt}$
3.	Acceleration $a = \frac{dv}{dt}$	Angular acceleration $\alpha = \frac{d\omega}{dt}$
4.	Mass M	Moment of inertia I
5.	Force $F = Ma$	Torque $\tau = I\alpha$
6.	Work $dW = Fds$	Work $dW = \tau d\theta$
7.	Kinetic energy of a translational motion $K_T = \frac{Mv^2}{2}$	Kinetic energy of a rotational motion $K_R = \frac{I\omega^2}{2}$
8.	Power $P = Fv$	Power $P = \tau\omega$
9.	Linear momentum $p = Mv$	Angular momentum $L = I\omega$
10.	Equations of translational motion (i) $v = u + at$ (ii) $s = ut + \frac{1}{2}at^2$ (iii) $v^2 - u^2 = 2as$ (iv) $s_{nth} = u + \frac{a}{2}(2n-1)$	Equations of rotational motion (i) $\omega = \omega_0 + \alpha t$ (ii) $\theta = \omega_0 t + \frac{1}{2}\alpha t^2$ (iii) $\omega^2 - \omega_0^2 = 2\alpha\theta$ (iv) $\theta_{nth} = \omega_0 + \frac{\alpha}{2}(2n-1)$

Moment of Inertia

The property of a body by virtue of which it opposes any change in its state of rest or of rotation is defined as its moment of inertia. The moment of inertia of a particle in rotational is equal to the product of its mass and square of distance from the axis.

$$I = mr^2$$

where m is the mass of the particle and r is the distance of the particle from axis of rotation.

Moment of inertia of a system of particles depends on

- Axis of rotation
- Mass of the system
- Distribution of mass in the body

About a particular axis of rotation, moment of inertia of a rigid body is constant.

Moment of inertia plays same role in rotational motion as mass plays in translational motion.

Moment of inertia is a scalar quantity. Its SI unit is kg m^2 and its dimensional formula is $[ML^2T^0]$.

Radius of Gyration

It is defined as the distance from the axis of rotation at which, if whole mass of the body were supposed to be concentrated, the moment of inertia would be same as with the actual distribution of the mass of body into small particles.

$$\text{Radius of gyration } K = \sqrt{\frac{I}{M}}$$

The moment of inertia of a body about a given axis is equal to the product of mass of the body and square of its radius of gyration about that axis. *i.e.*, $I = MK^2$.

The SI unit of radius of gyration is metre and its dimensional formula is $[M^0LT^0]$.

Radius of gyration of a body about an axis of rotation may also be defined as the root mean square distance of the particles from the axis of rotation.

$$i.e.,\ K = \sqrt{\frac{r_1^2 + r_2^2 + ... + r_N^2}{N}}$$

Theorems of moment of inertia

Theorem of perpendicular axis : The moment of inertia of a planar lamina about an axis perpendicular to its plane is equal to the sum of its moments of inertia about two perpendicular axes concurrent with perpendicular axis and lying in the plane of the body.

$$I_z = I_x + I_y$$

where x and y are two perpendicular axes in the plane and z axis is perpendicular to its plane.

Theorem of parallel axes : The moment of inertia of a body about any axis is equal to the sum of the moment of inertia of the body about a parallel axis passing through its centre of mass and the product of its mass and the square of the distance between the two parallel axes.

$$I = I_{CM} + Md^2$$

where I_{CM} is the moment of inertia of the body about an axis passing through the centre of mass and d is the perpendicular distance between two parallel axes.

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Moment of inertia and radius of gyration of some regular bodies about specific axis is given below:

S.No.	Body	Axis of rotation	Moment of inertia (I)	Radius of gyration (K)
1.	Uniform circular ring of mass M and radius R	(i) about an axis passing through its centre and perpendicular to its plane	MR^2	R
		(ii) about a diameter	$\frac{1}{2}MR^2$	$\frac{R}{\sqrt{2}}$
		(iii) about a tangent in its own plane	$\frac{3}{2}MR^2$	$\sqrt{\frac{3}{2}}R$
		(iv) about a tangent perpendicular to its plane	$2MR^2$	$R\sqrt{2}$
2.	Uniform circular disc of mass M and radius R	(i) about an axis passing through its centre and perpendicular to its plane	$\frac{1}{2}MR^2$	$\frac{R}{\sqrt{2}}$
		(ii) about a diameter	$\frac{1}{4}MR^2$	$\frac{R}{2}$
		(iii) about a tangent in its own plane	$\frac{5}{4}MR^2$	$\sqrt{5}\frac{R}{2}$
		(iv) about a tangent perpendicular to its own plane	$\frac{3}{2}MR^2$	$\sqrt{\frac{3}{2}}R$
3.	Solid sphere of radius R and mass M	(i) about its diameter	$\frac{2}{5}MR^2$	$\sqrt{\frac{2}{5}}R$
		(ii) about a tangential axis	$\frac{7}{5}MR^2$	$\sqrt{\frac{7}{5}}R$
4.	Hollow sphere of radius R and mass M	(i) about its diameter	$\frac{2}{3}MR^2$	$\sqrt{\frac{2}{3}}R$
		(ii) about a tangential axis	$\frac{5}{3}MR^2$	$\sqrt{\frac{5}{3}}R$
5.	Solid cylinder of length l, radius R and mass M	(i) about its own axis	$\frac{1}{2}MR^2$	$\frac{R}{\sqrt{2}}$
		(ii) about an axis passing through its centre and perpendicular to its own axis	$M\left[\frac{l^2}{12}+\frac{R^2}{4}\right]$	$\sqrt{\frac{l^2}{12}+\frac{R^2}{4}}$
		(iii) about the diameter of one of the faces of cylinder	$M\left[\frac{l^2}{3}+\frac{R^2}{4}\right]$	$\sqrt{\frac{l^2}{3}+\frac{R^2}{4}}$
6.	Hollow cylinder of mass M, length l and radius R	(i) about its own axis	MR^2	R
		(ii) about an axis passing through its centre and perpendicular to its own axis	$M\left(\frac{R^2}{2}+\frac{l^2}{12}\right)$	$\sqrt{\frac{R^2}{2}+\frac{l^2}{12}}$
7.	Thin rod of length L	(i) about an axis through its centre and perpendicular to the rod	$\frac{ML^2}{12}$	$\frac{L}{\sqrt{12}}$
		(ii) about an axis through one end and perpendicular to the rod	$\frac{ML^2}{3}$	$\frac{L}{\sqrt{3}}$

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8.	Rectangular lamina of length l and breadth b	about an axis passing through its centre and perpendicular to its plane	$M\left[\frac{l^2+b^2}{12}\right]$	$\sqrt{\frac{l^2+b^2}{12}}$
9.	Uniform cone of radius R and height h	about an axis through its centre and joining its vertex to centre of base	$\frac{3}{10}MR^2$	$R\sqrt{\frac{3}{10}}$
10.	Parallelopiped of length l, breadth b and height h, mass M	about its central axis	$M\left(\frac{l^2+b^2}{12}\right)$	$\sqrt{\frac{l^2+b^2}{12}}$

- Relation between angular momentum and moment of inertia
  Angular momentum $L = I\omega$
- Kinetic energy of rotational motion, $K_R = \frac{1}{2}I\omega^2$.
- Kinetic energy of a rolling body = ranslation kinetic energy (K_T) + rotational kinetic energy (K_R)
  $$= \frac{1}{2}Mv^2 + \frac{1}{2}I\omega^2 = \frac{1}{2}Mv^2\left[1+\frac{K^2}{R^2}\right]$$
- When a body rolls down an inclined plane of inclination θ without slipping its velocity at bottom of incline is given by
  $$v = \sqrt{\frac{2gh}{1+\frac{K^2}{R^2}}}$$
  where h is the height of the incline.
- When a body rolls down on an inclined plane without slipping, its acceleration down the inclined plane is given by
  $$a = \frac{g\sin\theta}{1+\frac{K^2}{R^2}}$$
- When a body rolls down on an inclined plane without slipping, time taken by the body to reach the bottom is given by
  $$t = \sqrt{\frac{2l\left(1+\frac{K^2}{R^2}\right)}{g\sin\theta}}$$
  where l is the length of the inclined plane.

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EXAM DRILL

1. A horizontal rod rotates about a vertical axis through one end. A ring, which can slide along the rod without friction, is initially close to the axis and then slides to the other end of the rod. In this process, which of the following quantities will be conserved?
[L = angular momentum, K_T = total kinetic energy, K_R = rotational kinetic energy]
(a) L only (b) L and K_T only
(c) L and K_R only (d) K_T only

2. The ratio of radii of gyration of a circular disc and a circular ring of the same radii about a tangential axis perpendicular to plane of disc or ring is
(a) 1 : 2 (b) $\sqrt{5}:\sqrt{6}$ (c) 2 : 3 (d) $\sqrt{3}:2$

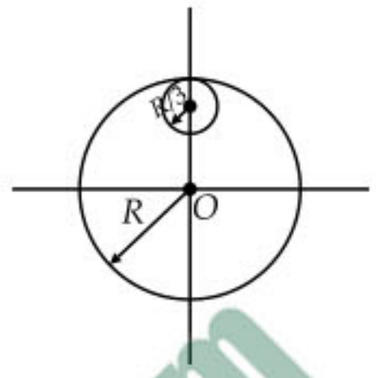
3. A body is rotating with angular velocity $\vec{\omega}=(3\hat{i}-4\hat{j}+\hat{k})$. The linear velocity of a point having position vector $\vec{r}=(5\hat{i}-6\hat{j}+6\hat{k})$ is
(a) $6\hat{i}+2\hat{j}-3\hat{k}$ (b) $18\hat{i}+3\hat{j}-2\hat{k}$
(c) $-18\hat{i}-13\hat{j}+2\hat{k}$ (d) $6\hat{i}-2\hat{j}+8\hat{k}$

4. A circular platform is mounted on a vertical frictionless axle. Its radius is r = 2 m and its moment of inertia I = 200 kg m^2. It is initially at rest. A 70 kg man stands on the edge of the platform and begins to walk along the edge at speed v_0 = 1.0 m s^{-1} relative to the ground. The angular velocity of the platform is
(a) 1.2 rad s^{-1} (b) 0.4 rad s^{-1}
(c) 0.7 rad s^{-1} (d) 2.0 rad s^{-1}

5. Particles of masses m, $2m$, $3m$ … nm grams are placed on the same line at distance l, $2l$, $3l$ … nl cm from a fixed point. The distance of centre of mass of the particles from the fixed point in centimetre is
(a) $\frac{(2n+1)l}{3}$ (b) $\frac{l}{n+1}$
(c) $\frac{n(n^2+1)l}{2}$ (d) $\frac{2l}{n(n^2+1)}$

6. A uniform solid cylinder has a radius R and length L. If the moment of inertia of this cylinder about an axis passing through its centre and normal to its circular face is equal to the moment of inertia of the same cylinder about an axis passing through its centre and perpendicular to its length, then
(a) $L=R$ (b) $L=\sqrt{3}R$
(c) $L=\frac{R}{\sqrt{3}}$ (d) $L=\sqrt{\frac{3}{2}}R$

7. From a circular disc of radius R and mass $9M$, a small disc of radius $\frac{R}{3}$ is removed as shown in figure. The moment of inertia of the remaining disc about an axis perpendicular to the plane of the disc and passing through O is



(a) $4MR^2$ (b) $\frac{40}{9}MR^2$
(c) $40MR^2$ (d) $\frac{37}{9}MR^2$

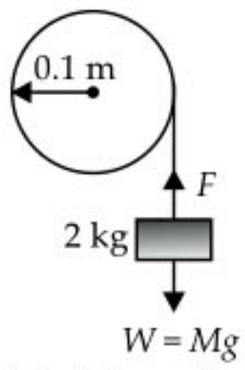
8. A thin rod of length L and mass M is bent at its midpoint into two halves so that the angle between them is 90°. The moment of inertia of the bent rod about an axis passing through the bending point and perpendicular to the plane defined by the two halves of the rod is
(a) $\frac{ML^2}{24}$ (b) $\frac{ML^2}{12}$ (c) $\frac{ML^2}{6}$ (d) $\frac{\sqrt{2}ML^2}{24}$

9. A solid cylinder of mass 3 kg is rolling on a horizontal surface with velocity 4 m s^{-1}. It collides with a horizontal spring of force constant 200 N m^{-1}. The maximum compression produced in the spring will be
(a) 0.5 m (b) 0.6 m (c) 0.7 m (d) 0.2 m

10. A uniform thin bar of mass $6m$ and length $12L$ is bent to make a regular hexagon. Its moment of inertia about an axis passing through the centre of mass and perpendicular to the plane of hexagon is
(a) $20mL^2$ (b) $6mL^2$ (c) $\frac{12}{5}mL^2$ (d) $30mL^2$

11. Three particles of masses 1 kg, 2 kg and 3 kg are situated at the corners of an equilateral triangle of side b. The coordinates of the centre of mass are
(a) $\left[0,\frac{7b}{12},\frac{3\sqrt{3}b}{12}\right]$ (b) $\left[\frac{3\sqrt{3}b}{12},\frac{7b}{12},0\right]$
(c) $\left[\frac{7b}{12},\frac{3\sqrt{3}b}{12},0\right]$ (d) $\left[\frac{7b}{12},0,\frac{3\sqrt{3}b}{12}\right]$

12. The moment of inertia of a solid flywheel about its axis is 0.1 kg m^2. A tangential force of 2 kg wt. is applied round the circumference of the flywheel with the help of a string and mass arrangement as shown in the figure. If the radius of the wheel is 0.1 m, find the acceleration of the mass



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(a) 163.3 rad s^{-2} (b) 16.3 rad s^{-2}
(c) 81.66 rad s^{-2} (d) 8.16 rad s^{-2}

13. A thin circular disc of mass M and radius R is rotating in a horizontal plane about an axis passing through its centre and perpendicular to its plane with an angular velocity ω. If another disc of same dimensions but of mass $M/4$ is placed gently on the first disc co-axially, then the new angular velocity of the system is

(a) $\frac{5}{4}\omega$ (b) $\frac{2}{3}\omega$
(c) $\frac{4}{5}\omega$ (d) $\frac{3}{2}\omega$

14. A flywheel rotates with a uniform angular acceleration. Its angular velocity increases from 20π rad s^{-1} to 40π rad s^{-1} in 10 s. How many rotations did it make in this period?

(a) 80 (b) 100
(c) 120 (d) 150

15. An electric motor drill, rated 350 W has an efficiency of 35%. The torque produced, if it is working at 3000 rpm.

(a) 0.25 N m (b) 0.35 N m
(c) 0.39 N m (d) 0.30 N m

16. A rope is wound round a hollow cylinder of mass 3 kg and radius 40 cm. If the rope is pulled with a force of 30 N, angular acceleration of the cylinder will be

(a) 10 rad s^{-2} (b) 15 rad s^{-2}
(c) 20 rad s^{-2} (d) 25 rad s^{-2}

17. The moment of inertia of a body about a given axis is 1.2 kg m^2. Initially, the body is at rest. In order to produce a rotational kinetic energy of 6000 joule, an angular acceleration of 25 rad s^{-2} must be applied about that axis for a duration of

(a) 4 s (b) 2 s
(c) 8 s (d) 10 s

18. Three point masses m_1, m_2, m_3, are located at the vertices of an equilateral triangle of length a. The moment of inertia of system about an axis along the altitude of the triangle passing through m_1 is

(a) $(m_2+m_3)\frac{a^2}{4}$ (b) $(m_1+m_2+m_3)a^2$
(c) $(m_1+m_2)\frac{a^2}{2}$ (d) $(m_2+m_3)a^2$

19. A solid sphere of mass M, radius R and having moment of inertia about an axis passing through the centre of mass as I, is recast into a disc of thickness t, whose moment of inertia about an axis passing through its edge and perpendicular to its plane remains I. Then, radius of the disc will be

(a) $\frac{2R}{\sqrt{15}}$ (b) $R\sqrt{\frac{2}{15}}$
(c) $\frac{4R}{\sqrt{15}}$ (d) $\frac{R}{4}$

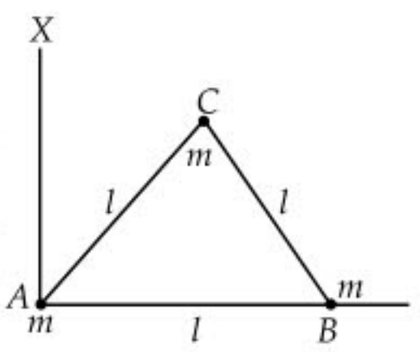
20. Two rings of radius R and nR made up of same material have the ratio of moment of inertia about an axis passing through centre as 1 : 8. The value of n is

(a) 2 (b) $2\sqrt{2}$
(c) 4 (d) $\frac{1}{2}$

21. A wire of length l and mass m is bent in the form of a rectangle $ABCD$ with $\frac{AB}{BC}=2$. The moment of inertia of this wire frame about the side BC is

(a) $\frac{11}{252}ml^2$ (b) $\frac{8}{203}ml^2$
(c) $\frac{5}{136}ml^2$ (d) $\frac{7}{162}ml^2$

22. Three particles, each of mass m gram, are situated at the vertices of an equilateral triangle ABC of side l cm as shown in figure. The moment of inertia of the system about a line AX perpendicular to AB and in the plane of ABC, in gram cm^2 will be



(a) $\frac{5}{4}ml^2$ (b) $\frac{3}{2}ml^2$
(c) $\frac{3}{4}ml^2$ (d) $2\,ml^2$

23. A mass M is moving with a constant velocity parallel to the x-axis. Its angular momentum w.r.t. the origin

(a) is zero (b) remains constant
(c) goes on increasing (d) goes on decreasing

24. A force $\vec{F}=\alpha\hat{i}+3\hat{j}+6\hat{k}$ is acting at a point $\vec{r}=2\hat{i}-6\hat{j}-12\hat{k}$. The value of α for which angular momentum about origin is conserved is

(a) 1 (b) –1
(c) 2 (d) zero

25. Two equal and opposite forces act on a rigid body at a certain distance. Then

(a) the body is in equilibrium.
(b) the body will rotate about its centre of mass.
(c) the body may rotate about any point other than its centre of mass.
(d) the body cannot rotate about its centre of mass.

26. The moment of inertia of a disc, of mass M and radius R, about an axis which is a tangent and parallel to its diameter is

(a) $\frac{1}{2}MR^2$ (b) $\frac{3}{4}MR^2$
(c) $\frac{1}{4}MR^2$ (d) $\frac{5}{4}MR^2$

27. A ball rolls without slipping. The radius of gyration of the ball about an axis passing through its centre of mass is K. If radius of the ball be R, then the fraction of total energy associated with its rotation will be

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(a) $\frac{K^2+R^2}{R^2}$ (b) $\frac{K^2}{R^2}$

(c) $\frac{K^2}{K^2+R^2}$ (d) $\frac{R^2}{K^2+R^2}$

28. A circular disc of radius R is removed from a bigger circular disc of radius $2R$, such that the circumferences of the discs coincide. The centre of mass of the new disc is αR from the centre of the bigger disc. The value of α is

(a) $\frac{1}{4}$ (b) $\frac{1}{3}$

(c) $\frac{1}{2}$ (d) $\frac{1}{6}$

29. Two particles of equal mass have velocities $\vec{v}_1 = 4\hat{i}\ \text{m s}^{-1}$ and $\vec{v}_2 = 4\hat{j}\ \text{m s}^{-1}$. First particles has an acceleration $\vec{a}_1 = (5\hat{i}+5\hat{j})\ \text{m s}^{-2}$ while the acceleration of the other particle is zero. The centre of mass of the two particles moves in a path of

(a) straight line (b) parabola

(c) circle (d) ellipse

30. A billiard ball is hit by a cue at a height h above the centre. It acquires a linear velocity v_0. Mass of the ball is m and radius is r. The angular velocity ω_0 acquired by the ball is

(a) $\frac{2v_0h}{5r^2}$ (b) $\frac{5v_0h}{2r^2}$

(c) $\frac{2v_0r^2}{5h}$ (d) $\frac{5v_0r^2}{2h}$

31. Two particles of mass 1 kg and 3 kg have position vectors $2\hat{i}+3\hat{j}+4\hat{k}$ and $-2\hat{i}+3\hat{j}-4\hat{k}$ respectively. The centre of mass has a position vector

(a) $\hat{i}+3\hat{j}-2\hat{k}$ (b) $-\hat{i}-3\hat{j}-2\hat{k}$

(c) $-\hat{i}+3\hat{j}+2\hat{k}$ (d) $-\hat{i}+3\hat{j}-2\hat{k}$

32. Circular disc of mass 2 kg and radius 1 m is rotating about an axis perpendicular to its plane and passing through its centre of mass with a rotational kinetic energy of 8 J. The angular momentum in (J s) is

(a) 8 (b) 4

(c) 2 (d) 1

33. Two bodies have their moments of inertia I and $2I$ respectively about their axis of rotation. If their kinetic energies of rotation are equal, their angular momenta will be in the ratio

(a) 1 : 2 (b) $\sqrt{2}:1$

(c) $1:\sqrt{2}$ (d) 2 : 1

34. Angular momentum of the particle rotating with a central force is constant due to

(a) constant torque

(b) constant force

(c) constant linear momentum

(d) zero torque

35. The diameter of a flywheel is 1 m. It has a mass of 20 kg. It is rotating about its axis with a speed of 120 rotations in one minute. Its angular momentum in kg $\text{m}^2\ \text{s}^{-1}$ is

(a) 13.4 (b) 31.4

(c) 41.4 (d) 43.4

36. A carpet of mass M, made of an extensible material is rolled along its length in the form of a cylinder of radius R and kept on a rough floor. If the carpet is unrolled, without sliding to a radius $R/2$, the decrease in potential energy is

(a) $\frac{1}{2}MgR$ (b) $\frac{7}{8}MgR$

(c) $\frac{5}{8}MgR$ (d) $\frac{3}{4}MgR$

37. Four particles each of mass m are lying symmetrically on the rim of a disc of mass M and radius R. The moment of inertia of this system about an axis passing through one of the particle and perpendicular to plane of disc is

(a) $16mR^2$ (b) $(3M+16m)\frac{R^2}{2}$

(c) $(3m+12M)\frac{R^2}{2}$ (d) zero

38. Two bodies of 6 kg and 4 kg masses have their velocity $5\hat{i}-2\hat{j}+10\hat{k}$ and $10\hat{i}-2\hat{j}+5\hat{k}$ respectively. Then the velocity of their centre of mass is

(a) $5\hat{i}+2\hat{j}-8\hat{k}$ (b) $7\hat{i}+2\hat{j}-8\hat{k}$

(c) $7\hat{i}-2\hat{j}+8\hat{k}$ (d) $5\hat{i}-2\hat{j}+8\hat{k}$

39. Two blocks of masses 10 kg and 4 kg connected by a spring of negligible mass and placed on a frictionless horizontal surface. An impulse gives a velocity of 14 m s^{-1} to the heavier block in the direction of the lighter block. The velocity of the centre of mass is

(a) 30 m s^{-1} (b) 20 m s^{-1}

(c) 10 m s^{-1} (d) 5 m s^{-1}

40. A train of mass M is moving on a circular track of radius R with constant speed v. The length of the train is half of the perimeter of the track. The linear momentum of the train will be

(a) 0 (b) $\frac{2Mv}{\pi}$

(c) MvR (d) Mv

41. Moment of inertia of ring about its diameter is I. Then, moment of inertia about an axis passing through centre perpendicular to its plane is

(a) $2I$ (b) $\frac{I}{2}$

(c) $\frac{3}{2}I$ (d) I

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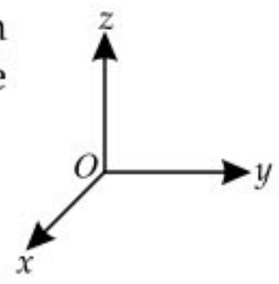
42. A force of $-F\hat{k}$ acts on O, the origin of the coordinate system. The torque about the point (1, –1) is



(a) $-F(\hat{i}+\hat{j})$
(b) $F(\hat{i}+\hat{j})$
(c) $-F(\hat{i}-\hat{j})$
(d) $F(\hat{i}-\hat{j})$

43. Three identical thin rods each of length l and mass M are joined together to form a letter H. What is the moment of inertia of the system about one of the sides of H?

(a) $\frac{Ml^2}{6}$ (b) $\frac{Ml^2}{4}$ (c) $\frac{2}{3}Ml^2$ (d) $\frac{4}{3}Ml^2$

44. The radius of gyration of a solid cylinder of mass M and radius R about its own axis is

(a) $\frac{R}{\sqrt{2}}$ (b) $\frac{R}{2}$
(c) $\frac{R}{\sqrt{3}}$ (d) $\frac{R}{3}$

45. The centre of mass of three bodies each of mass 1 kg located at the points (0, 0), (3, 0) and (0, 4) in the x-y plane is

(a) $\left(\frac{4}{3}, 1\right)$ (b) $\left(\frac{1}{3}, \frac{2}{3}\right)$
(c) $\left(\frac{1}{2}, \frac{1}{2}\right)$ (d) $\left(1, \frac{4}{3}\right)$

DAY 06 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____

(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (b) : As no external torque acts on the system, its angular momentum is conserved. Since there is no loss of energy due to friction, the total energy is conserved. However, the ring acquires some translational kinetic energy as it slides outwards, and hence rotational kinetic energy is not conserved.

2. (d) : Radius of gyration

$$K = \sqrt{\frac{I}{m}}$$

$$K_{\text{disc}} = \sqrt{\frac{\frac{1}{2}mR^2 + mR^2}{m}} = \sqrt{\frac{3}{2}}R$$

$$K_{\text{ring}} = \sqrt{\frac{mR^2 + mR^2}{m}} = \sqrt{2}R$$

$$\frac{K_{\text{disc}}}{K_{\text{ring}}} = \frac{\sqrt{\frac{3}{2}}}{\sqrt{2}} = \frac{\sqrt{3}}{2}$$

3. (c) : Here, $\vec{\omega} = 3\hat{i} - 4\hat{j} + \hat{k}$

$$\vec{r} = 5\hat{i} - 6\hat{j} + 6\hat{k}$$

As $\vec{v} = \vec{\omega} \times \vec{r}$

$$= \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 3 & -4 & 1 \\ 5 & -6 & 6 \end{vmatrix}$$

$$= \hat{i}(-24 - (-6)) + \hat{j}(5 - 18) + \hat{k}(-18 - (-20))$$

$$= -18\hat{i} - 13\hat{j} + 2\hat{k}$$

4. (c) : As the system is initially at rest, therefore, initial angular momentum, $L_i = 0$.

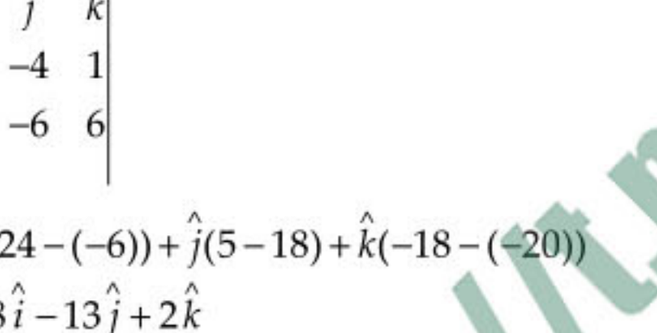
According to the law of conservation of angular momentum, final angular momentum, $L_f = 0$

$\therefore$ Angular momentum of man = Angular momentum of platform in opposite direction

i.e., $mv_0 r = I\omega$

or $$\omega = \frac{mv_0 r}{I} = \frac{70\,(1.0)(2)}{200} = 0.7 \text{ rad s}^{-1}$$

5. (a) :



The distance of centre of mass of given configuration of the particles from the fixed point O is

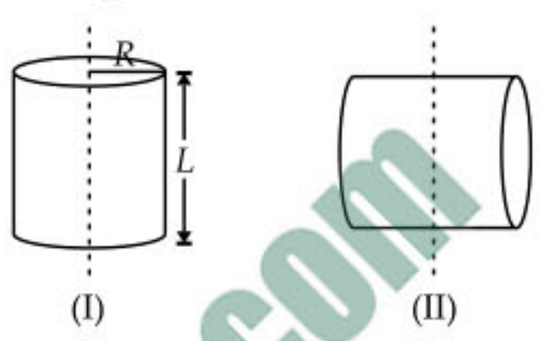
$$X_{\text{CM}} = \frac{m_1x_1 + m_2x_2 + m_3x_3 + \ldots + m_nx_n}{m_1 + m_2 + m_3 + \ldots + m_n}$$

$$X_{\text{CM}} = \frac{(m)(l) + (2m)(2l) + (3m)(3l) + \ldots + (nm)(nl)}{m + 2m + 3m + \ldots + nm}$$

$$= \frac{ml\,[1^2 + 2^2 + 3^2 + \ldots + n^2]}{m\,[1 + 2 + 3 + \ldots + n]}$$

$$= \frac{\frac{(l)(n)(n+1)(2n+1)}{6}}{\frac{(n)(n+1)}{2}} = \frac{(2n+1)l}{3} \text{ cm}$$

6. (b) :



(I) Moment of inertia of a cylinder about an axis passing through its centre and normal to its circular face $= \frac{MR^2}{2}$

(II) Moment of inertia of the same cylinder about an axis passing through its centre and perpendicular to its length

$$= M\left(\frac{L^2}{12} + \frac{R^2}{4}\right)$$

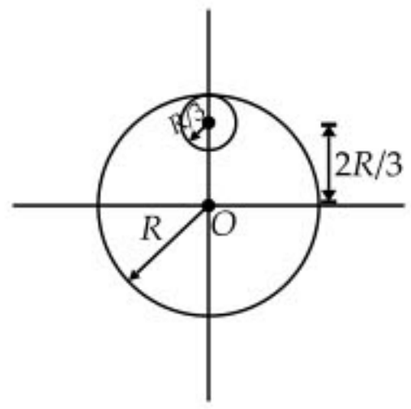
According to question

$$\frac{ML^2}{12} + \frac{MR^2}{4} = \frac{MR^2}{2} \quad \text{or} \quad L = \sqrt{3}R$$

7. (a) : Mass per unit area of disc $= \frac{9M}{\pi R^2}$

Mass of removed portion of disc

$$= \frac{9M}{\pi R^2} \times \pi\left(\frac{R}{3}\right)^2 = M$$



Moment of inertia of removed portion about an axis passing through centre of disc and perpendicular to the plane of disc, using theorem of parallel axes is

$$I_1 = \frac{M}{2}\left(\frac{R}{3}\right)^2 + M\left(\frac{2R}{3}\right)^2 = \frac{1}{2}MR^2$$

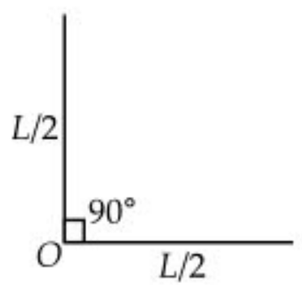
When portion of disc would not have been removed, then the moment of inertia of complete disc about the given axis is

$$I_2 = \frac{9}{2}MR^2$$

So moment of inertia of the disc with removed portion, about the given axis is

$$I = I_2 - I_1 = \frac{9}{2}MR^2 - \frac{1}{2}MR^2 = 4MR^2$$

8. (b) : Since rod is bent at the middle, so each part of it will have same length $\left(\frac{L}{2}\right)$ and mass $\left(\frac{M}{2}\right)$ as shown.



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Moment of inertia through of each part through its one end

$$=\frac{1}{3}\left(\frac{M}{2}\right)\left(\frac{L}{2}\right)^2$$

Hence, moment of inertia of bend rod about an axis passing through O and perpendicular to the plane is

$$I=2\left(\frac{1}{3}\left(\frac{M}{2}\right)\left(\frac{L}{2}\right)^2\right)=\frac{1}{12}ML^2$$

9. (b) : Here, $m = 3$ kg, $v = 4$ m s^{-1}
$k = 200$ N m^{-1}, $x = ?$

The compression will be maximum, when
Gain in potential energy of spring
= Loss in total kinetic energy of rolling cylinder

$$\frac{1}{2}kx^2=\frac{1}{2}mv^2+\frac{1}{2}I\omega^2$$

$$=\frac{1}{2}mv^2+\frac{1}{2}\left(\frac{1}{2}mr^2\right)\omega^2 \quad (\because \text{For solid cylinder } I=\frac{1}{2}mr^2)$$

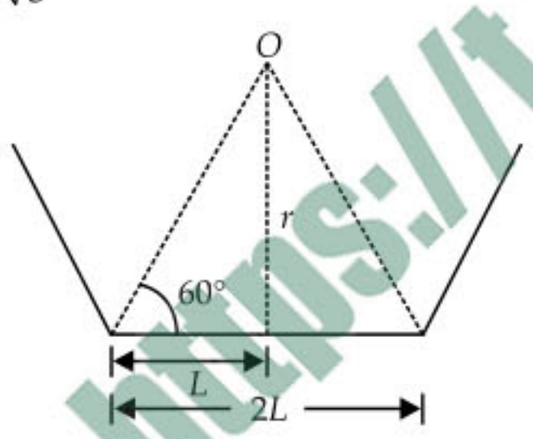
$$=\frac{1}{2}mv^2+\frac{1}{4}mv^2 \quad (\because v=r\omega)$$

$$\frac{1}{2}kx^2=\frac{3}{4}mv^2$$

$$x=\sqrt{\frac{3}{2}\frac{m}{k}}\times v=\sqrt{\frac{3}{2}\times\frac{3}{200}}\times 4=\frac{3\times 4}{20}$$

$x = 0.6$ m

10. (a) : Length of each side of hexagon $= 2L$
Mass of each side $= m$
Let O be centre of mass of hexagon.
Therefore, perpendicular distance of O from each side
$r = L\tan 60° = L\sqrt{3}$

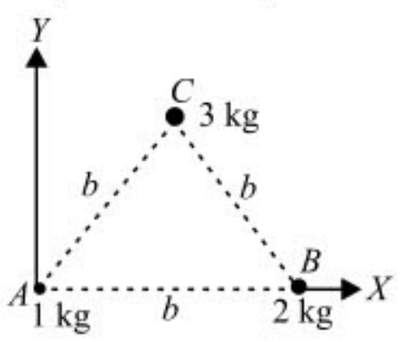


The desired moment of inertia of hexagon about O is
$I = 6\,[I_{\text{one side}}]$

$$=6\left[\frac{m(2L)^2}{12}+mr^2\right]=6\left[\frac{mL^2}{3}+m(L\sqrt{3})^2\right]$$

$$=6\left[\frac{mL^2}{3}+3mL^2\right]=20mL^2$$

11. (c) : The coordinates of points A, B and C are $(0, 0, 0)$, $(b, 0, 0)$ and $\left(\frac{b}{2}, \frac{b\sqrt{3}}{2}, 0\right)$ respectively.



Now as the triangle in XY plane, *i.e.*, Z coordinate of all the masses is zero,
so $Z_{CM} = 0$.

$$\text{Now, } X_{CM}=\frac{1\times 0+2\times b+3(b/2)}{1+2+3}=\frac{7b}{12}$$

$$Y_{CM}=\frac{1\times 0+2\times 0+3\sqrt{3}(b/2)}{1+2+3}=\frac{3\sqrt{3}b}{12}$$

So, the coordinates of centre of mass are

$$\left[\frac{7b}{12}, \frac{3\sqrt{3}b}{12}, 0\right]$$

12. (b) : Suppose a be the linear acceleration of the mass and T the tension in the string.
Hence,

$$Mg - T = Ma \quad \text{...(i)}$$

Let α be the angular acceleration of the flywheel. The couple applied to the flywheel is

$$I\alpha = TR \text{ or } T=\frac{I\alpha}{R} \quad \text{...(ii)}$$

Now we know that $a = R\alpha$ ...(iii)
Putting (ii) and (iii) in eq. (i), we get

$$Mg-\frac{I\alpha}{R}=MR\alpha$$

$$\therefore \quad \alpha=\frac{MgR}{I+MR^2} \quad \text{...(iv)}$$

$$=\frac{2\times 9.8\times 0.1}{0.1+2\times(0.1)^2}=16.33 \text{ rad s}^{-2}$$

13. (c) : According to conservation of angular momentum

$$I_1\omega_1 = I_2\omega_2 \quad (\because \text{Here } \omega_1=\omega)$$

$$\text{or} \quad \frac{1}{2}MR^2\omega=\left[\frac{1}{2}MR^2+\frac{1}{2}\left(\frac{M}{4}\right)R^2\right]\omega_2$$

$$\therefore \quad \omega_2=\frac{4}{5}\omega$$

14. (d) : Here, $\omega_1 = 20\pi$ rad s^{-1}, $\omega_2 = 40\pi$ rad s^{-1},
$t = 10$ s

As $\omega_2 = \omega_1 + \alpha t$

$\therefore \quad 40\pi = 20\pi + \alpha \times 10$ or $\alpha = 2\pi$ rad s^{-2}

From, $\omega_2^2 - \omega_1^2 = 2\alpha\theta$

$$(40\pi)^2-(20\pi)^2=2\times 2\pi\theta$$

$$\text{or} \quad \theta=\frac{1200\pi^2}{4\pi}=300\pi$$

Number of rotations completed

$$=\frac{\theta}{2\pi}=\frac{300\pi}{2\pi}=150$$

15. (c) : Angular velocity of the motor drill,

$$\omega=\frac{2\pi\upsilon}{60}=\frac{2\pi\times 3000}{60}$$

Let τ be the torque produced by the motor.

$$\text{Power produced} = \tau\omega = \tau\times\frac{2\pi\times 3000}{60}$$

$$\text{Now,} \quad \tau\times\frac{2\pi\times 3000}{60}=35\% \text{ of } 350 \text{ W}$$

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or $\tau \times 2\pi \times 50 = \frac{35}{100} \times 350$

or $\tau = \frac{35 \times 350}{100 \times 2\pi \times 50} = 0.39$ N m

16. (d) : Moment of inertia of the hollow cylinder about its axis is

$I = MR^2 = 3 \times (0.40)^2 = 0.48$ kg m^2

Torque applied on the cylinder,

τ = force × moment arm

$= 30 \times 0.40 = 12$ N m

Angular acceleration of the cylinder,

$\alpha = \frac{\tau}{I} = \frac{12}{0.48} = 25$ rad s^{-2}

17. (a) : Rotational kinetic energy

$K_R = \frac{1}{2} I\omega^2 = \frac{1}{2} I(\alpha t)^2 = \frac{1}{2} I\alpha^2 t^2$

Substituting the given values, we get

$6000 = \frac{1}{2} \times 1.2 \times (25)^2 \times t^2$

or $t^2 = 16$ or $t = 4$ s

18. (a) : Perpendicular distance of m_2 and m_3 from altitude of triangle

$= a \cos 60° = \frac{a}{2}$

Moment of inertia of the system about the given axis is

$I = m_1 \times 0^2 + m_2\left(\frac{a}{2}\right)^2 + m_3\left(\frac{a}{2}\right)^2$

$= (m_2 + m_3)\frac{a^2}{4}$

19. (a) : Moment of inertia of solid sphere of mass M and radius R about an axis passing through the centre of mass is $I = \frac{2}{5}MR^2$.

Let the radius of the disc is r.

Moment of inertia of circular disc of radius r and mass M about an axis passing through the centre of mass and perpendicular to its plane $= \frac{1}{2}Mr^2$.

Using theorem of parallel axes, moment of inertia of disc about its edge is

$I' = \frac{1}{2}Mr^2 + Mr^2 = \frac{3}{2}Mr^2$

Given, $I = I'$

$\therefore \quad \frac{2}{5}MR^2 = \frac{3}{2}Mr^2$ or $r^2 = \frac{4}{15}R^2$ or $r = \frac{2R}{\sqrt{15}}$

20. (a) : The moment of inertia of circular ring whose axis of rotation is passing through its centre is,

$I = mR^2$

$\therefore \quad I_1 = m_1R^2$ and $I_2 = m_2(nR)^2$

Since, both have same density.

$\therefore \quad \frac{m_2}{2\pi(nR) \times A} = \frac{m_1}{2\pi R \times A}$

where A is cross-section area of ring.

$\therefore \quad m_2 = nm_1$

$\because \quad \frac{I_1}{I_2} = \frac{m_1R^2}{m_2(nR)^2} = \frac{m_1R^2}{m_1n(nR)^2} = \frac{1}{n^3}$

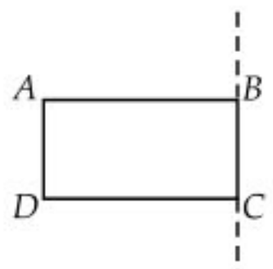
$\because \quad \frac{I_1}{I_2} = \frac{1}{8}$ (Given) $\quad \therefore \quad \frac{1}{8} = \frac{1}{n^3}$ or $n = 2$

21. (d) : $\frac{AB}{BC} = 2 \quad \therefore \quad AB = DC = \frac{l}{3}$

and $BC = AD = \frac{l}{6}$

Similarly, $m_{AB} = m_{DC} = \frac{m}{3}$

and $m_{BC} = m_{AD} = \frac{m}{6}$



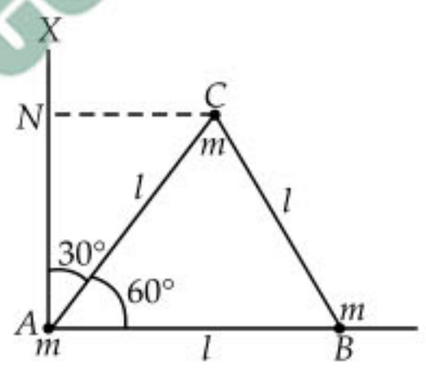
$\therefore$ Moment of inertia of the wire frame about the given axis is

$I = I_{AB} + I_{AD} + I_{DC} + I_{BC}$

$= \frac{1}{3}\left(\frac{m}{3}\right)\left(\frac{l}{3}\right)^2 + \left(\frac{m}{6}\right)\left(\frac{l}{3}\right)^2 + \frac{1}{3}\left(\frac{m}{3}\right)\left(\frac{l}{3}\right)^2 + 0$

$= \frac{ml^2}{81} + \frac{ml^2}{54} + \frac{ml^2}{81} = \frac{7}{162}ml^2$

22. (a) :



From figure,

$\sin 30° = \frac{CN}{CA} = \frac{CN}{l}$

$CN = l \sin 30° = \frac{l}{2}$

Moment of inertia of the system about the desired axis is

$I = m_A(0)^2 + m_B(l)^2 + m_C(CN)^2$

$= 0 + ml^2 + m\left(\frac{l}{2}\right)^2 = \frac{5}{4}ml^2$

23. (b)

24. (b) : Angular momentum, L = constant, when

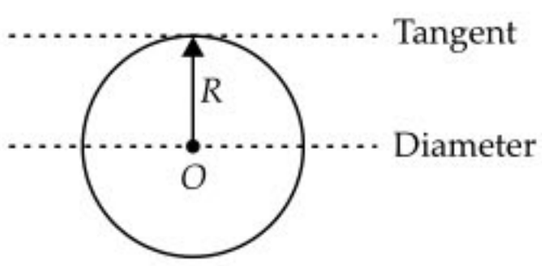
$\vec{\tau} = \vec{r} \times \vec{F} = 0$

i.e. $(2\hat{i} - 6\hat{j} - 12\hat{k}) \times (\alpha\hat{i} + 3\hat{j} + 6\hat{k}) = 0$

or $\begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 2 & -6 & -12 \\ \alpha & 3 & 6 \end{vmatrix} = 0$, which gives $\alpha = -1$

25. (b) : Net force on centre of mass is zero, *i.e.*, the centre mass cannot move at all. Hence, the body will rotate about centre of mass only.

26. (d) :



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Using the theorem of parallel axes,

$I_{\text{tangent}} = I_{\text{diameter}} + MR^2$

$$= \frac{MR^2}{4} + MR^2 = \frac{5}{4}MR^2$$

27. (c) : Total kinetic energy

= K.E. of translation + K.E. of rotation

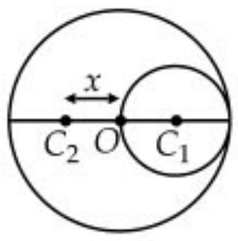
$$= \frac{1}{2}Mv^2 + \frac{1}{2}I\omega^2$$

$$= \frac{1}{2}Mv^2 + \frac{1}{2}MK^2\frac{v^2}{R^2} \quad (\because I = MK^2 \text{ and } v = \omega R)$$

$$= \frac{1}{2}Mv^2\left(1 + \frac{K^2}{R^2}\right)$$

$$\frac{\text{K.E. of rotation}}{\text{Total K.E.}} = \frac{\frac{1}{2}MK^2\frac{v^2}{R^2}}{\frac{1}{2}Mv^2\left(1+\frac{K^2}{R^2}\right)} = \frac{\frac{K^2}{R^2}}{1+\frac{K^2}{R^2}} = \frac{K^2}{K^2+R^2}$$

28. (b) : In figure,, O is the centre of circular disc of radius $2R$ and mass M.C_1 is centre of disc of radius R, which is removed. If σ is mass per unit area of disc, then



$M = \pi(2R)^2\sigma$

Mass of disc removed, $M_1 = \pi R^2\sigma = \frac{1}{4}M$

Mass of remaining disc, $M_2 = M - M_1$

$$= M - \frac{1}{4}M = \frac{3}{4}M$$

Let centre of mass of remining disc be at C_2 where $OC_2 = x$

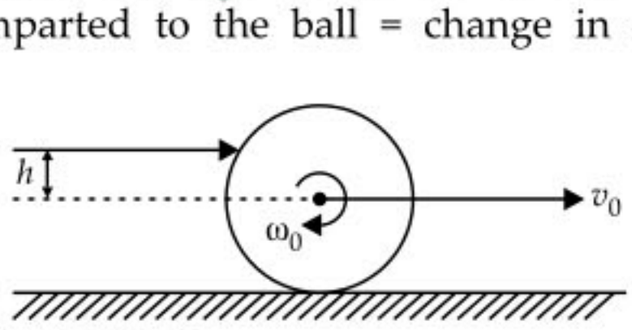
As $M_1 \times OC_1 = M_2 \times OC_2$

$$\therefore \quad \frac{M}{4}R = \frac{3M}{4}x$$

$$x = \frac{R}{3} = \alpha R \ \therefore \ \alpha = \frac{1}{3}$$

29. (a)

30. (b) : When the ball is hit by a cue, the linear impulse imparted to the ball = change in momentum $= mv_0$.



As is clear from figure,

Angular momentum = moment of momentum

$$I\omega_0 = (mv_0)h$$

$$\left(\frac{2}{5}mr^2\right)\omega_0 = (mv_0)h$$

$$\therefore \quad \omega_0 = \frac{5v_0h}{2r^2}$$

31. (d) : Here, $m_1 = 1$ kg, $m_2 = 3$ kg

$\vec{r}_1 = 2\hat{i} + 3\hat{j} + 4\hat{k}, r_2 = -2\hat{i} + 3\hat{j} - 4\hat{k}$

The position vector of the centre of mass is

$$\vec{r}_{\text{CM}} = \frac{m_1\vec{r}_1 + m_2\vec{r}_2}{m_1 + m_2}$$

$$= \frac{(1)(2\hat{i}+3\hat{j}+4\hat{k}) + (3)(-2\hat{i}+3\hat{j}-4\hat{k})}{1+3}$$

$$= \frac{2\hat{i}+3\hat{j}+4\hat{k}-6\hat{i}+9\hat{j}-12\hat{k}}{4}$$

$$= \frac{-4i+12j-8k}{4} = -\hat{i}+3\hat{j}-2\hat{k}$$

32. (b) : Here, Mass of the disc, $M = 2$ kg

Radius of the disc, $R = 1$ m

Moment of inertia of the disc about an axis perpendicular to, its plane and passing through its centre of mass is

$$I = \frac{1}{2}MR^2 = \frac{1}{2}\times(2\text{ kg})(1)^2 = 1\text{ kg m}^2$$

Kinetic energy of rotation,

$K_R = \frac{L^2}{2I}$ where L is the angular momentum

or $L = \sqrt{2K_RI} = \sqrt{2\times8\times1} = 4$ J s

33. (c) : As $K_{R_1} = K_{R_2}$

$$\therefore \quad \frac{1}{2}I_1\omega_1^2 = \frac{1}{2}I_2\omega_2^2$$

$$\text{or} \quad \frac{\omega_1}{\omega_2} = \sqrt{\frac{I_2}{I_1}} \quad \ldots(\text{i})$$

$$\frac{L_1}{L_2} = \frac{I_1\omega_1}{I_2\omega_2} = \frac{I_1}{I_2}\sqrt{\frac{I_2}{I_1}} = \sqrt{\frac{I_1}{I_2}} \quad (\text{Using (i)})$$

$$\frac{L_1}{L_2} = \sqrt{\frac{1}{2}} = \frac{1}{\sqrt{2}}$$

34. (d) : Torque due to central force is zero.

As $\tau = \frac{dL}{dt} = 0$

$\therefore \quad L = \text{constant}$

35. (b) : Here,

Diameter of a flywheel, $D = 1$ m

Radius of the flywheel, $R = \frac{D}{2} = \frac{1}{2}$ m

Mass of the flywheel, $M = 20$ kg

Angular speed of rotation,

$$\omega = 120\text{ rpm} = \frac{2\pi\times120}{60}\text{ rad s}^{-1} = 4\pi\text{ rad s}^{-1}$$

Moment of inertia of the flywheel about its axis,

$$I = \frac{1}{2}MR^2 = \frac{1}{2}(20\text{ kg})\left(\frac{1}{2}\text{ m}\right)^2$$

$$= 2.5\text{ kg m}^2$$

Angular momentum, $L = I\omega$

$$= (2.5)(4\pi)$$

$$= 10\pi$$

$$= 31.4\text{ kg m}^2\text{ s}^{-1}$$

36. (b) : The centre of mass of the whole carpet is originally at a height R above the floor. When the carpet

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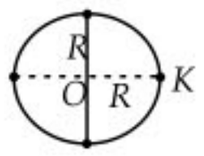
unrolls itself and has a radius $R/2$, the centre of mass is at a height $R/2$. The mass left over unrolled is $\frac{M\pi(R/2)^2}{\pi R^2} = \frac{M}{4}$

Decrease in potential energy

$$= MgR - \left(\frac{M}{4}\right)g\left(\frac{R}{2}\right) = \frac{7}{8}MgR$$

37. (b) : According to the theorem of parallel axes, moment of inertia of disc about an axis passing through K and perpendicular to plane of disc is

$$= \frac{1}{2}MR^2 + MR^2 = \frac{3}{2}MR^2$$



Total moment of inertia of the system

$$= \frac{3}{2}MR^2 + m(2R)^2 + m(\sqrt{2}R)^2 + m(\sqrt{2}R)^2$$

$$= (3M + 16m)\frac{R^2}{2}$$

38. (c) : Here, $m_1 = 6$ kg, $m_2 = 4$ kg

$\vec{v}_1 = 5\hat{i} - 2\hat{j} + 10\hat{k}$

$\vec{v}_2 = 10\hat{i} - 2\hat{j} + 5\hat{k}$

The velocity of the centre of mass is

$$\vec{v}_{CM} = \frac{m_1\vec{v}_1 + m_2\vec{v}_2}{m_1 + m_2}$$

$$= \frac{(6)(5\hat{i} - 2\hat{j} + 10\hat{k}) + 4(10\hat{i} - 2\hat{j} + 5\hat{k})}{6 + 4}$$

$$= \frac{30\hat{i} - 12\hat{j} + 60\hat{k} + 40\hat{i} - 8\hat{j} + 20\hat{k}}{10}$$

$$= \frac{70\hat{i} - 20\hat{j} + 80\hat{k}}{10} = 7\hat{i} - 2\hat{j} + 8\hat{k}$$

39. (c) : Here, $m_1 = 10$ kg, $m_2 = 4$ kg

$v_1 = 14\ \text{m s}^{-1}$, $v_2 = 0$

$$v_{CM} = \frac{m_1v_1 + m_2v_2}{m_1 + m_2}$$

$$v_{CM} = \frac{10 \times 14 + 4 \times 0}{10 + 4} = 10\ \text{m s}^{-1}$$

40. (b) **41. (a)**

42. (b) : Here, $\vec{F} = -F\hat{k}$; $\vec{r} = (\hat{i} - \hat{j})$

$$\therefore \quad \vec{\tau} = \vec{r} \times \vec{F} = (\hat{i} - \hat{j}) \times (-F\hat{k})$$

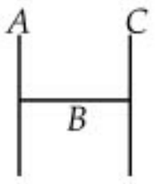
$$= -F(\hat{i} \times \hat{k} - \hat{j} \times \hat{k}) = -F(-\hat{j} - \hat{i})$$

$$\vec{\tau} = F(\hat{i} + \hat{j})$$

43. (d) : Moment of inertia of the system about rod A

$$I = I_A + I_B + I_C = 0 + \left(\frac{Ml^2}{12} + \frac{Ml^2}{4}\right) + Ml^2$$

$$= \frac{4}{3}Ml^2$$



44. (a) : The moment of inertia of a solid cylinder of mass M and radius R about its own axis is

$$I = \frac{MR^2}{2} \qquad ...(i)$$

As $I = MK^2$ ...(ii)

where K is the radius of gyration

From (i) and (ii), we get

$$K^2 = \frac{R^2}{2} \text{ or } K = \frac{R}{\sqrt{2}}$$

45. (d) : Here, $m_1 = 1$ kg, $(x_1, y_1) = (0, 0)$

$m_2 = 1$ kg, $(x_2, y_2) = (3, 0)$

$m_3 = 1$ kg, $(x_3, y_3) = (0, 4)$

$$x_{CM} = \frac{m_1x_1 + m_2x_2 + m_3x_3}{m_1 + m_2 + m_3}$$

$$= \frac{1 \times 0 + 1 \times 3 + 1 \times 0}{1 + 1 + 1} = 1$$

$$y_{CM} = \frac{m_1y_1 + m_2y_2 + m_3y_3}{m_1 + m_2 + m_3}$$

$$= \frac{1 \times 0 + 1 \times 0 + 1 \times 4}{1 + 1 + 1} = \frac{4}{3}$$

The coordinates of centre of mass are $\left(1, \frac{4}{3}\right)$.

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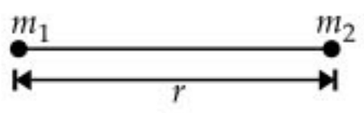
Gravitation

Newton's law of Gravitation

It states that every body in the universe attracts every other body with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. This force acts along the line joining the two bodies.

According to Newton's law of Gravitation,

$$F \propto \frac{m_1 m_2}{r^2} \quad \text{or} \quad F = \frac{G m_1 m_2}{r^2}$$



where G is a constant of proportionality and is called universal gravitational constant.

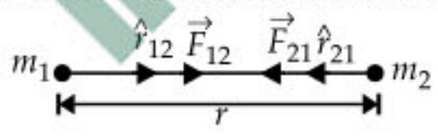
Universal gravitational constant G is a scalar quantity. Its value is same throughout the universe and is independent of the nature and size of the bodies as well as the nature of the medium between the bodies.

The value of G in SI system is 6.67×10^{-11} N m^2 kg^{-2} and in CGS system is 6.67×10^{-8} dyne cm^2 g^{-2}.

The dimensional formula for G is $[M^{-1}L^3T^{-2}]$.

The value of universal gravitational constant G was determined experimentally, first of all, by English scientist **Henry Cavendish** in 1798.

Newton's Law of Gravitation in Vector Form



$$\vec{F}_{12} = \frac{G m_1 m_2}{r^2} \hat{r}_{12} \text{ and } \vec{F}_{21} = \frac{G m_1 m_2}{r^2} \hat{r}_{21}$$

where $\vec{F}_{12}$ is the force on mass m_1 exerted by mass m_2 and vice-versa.

As $\hat{r}_{12} = -\hat{r}_{21}$

Thus $\vec{F}_{21} = -\frac{G m_1 m_2}{r^2} \hat{r}_{12}$

Comparing above, we get $\vec{F}_{12} = -\vec{F}_{21}$

Important Characteristics of Gravitational Force

The important characteristics of gravitational force are as follows :

- It is always attractive in nature.
- It obeys inverse square law.
- It is independent of nature of intervening medium.
- It is independent of the presence or absence of other bodies.
- It is independent of nature and size of the bodies, till their masses remain the same and the distance between their centres is fixed.
- It holds good over a wide range of distances. It is found true from interplanetary distances to interatomic distances.
- It forms action-reaction pair *i.e.* the gravitational forces between two bodies are equal in magnitude but opposite in direction and hence they obey Newton's third law of motion.
- It is a conservative force *i.e.* workdone by it is path independent.
- It is a central force *i.e.* it acts along the line joining the centre of the two interacting bodies.

Acceleration due to gravity

Acceleration produced in a body due to the force of gravity is called as acceleration due to gravity. It is denoted by symbol 'g' and mathematically it is given by

$$g = \frac{G M_e}{r^2}$$

where M_e is the mass of the earth and r is the distance of the body from the centre of the earth. If the body on the surface of the earth *i.e.* $r = R_e$ (radius of the earth), then

$$g = \frac{G M_e}{R_e^2}$$

- It is also defined as the acceleration produced in the body while falling freely under the effect of gravity alone.
- It is a vector quantity. It is directed towards the centre of earth. Its SI unit is m s^{-2} or N kg^{-1} and its dimensional formula is $[M^0LT^{-2}]$.
- The value of g on the surface of earth is taken to be 9.8 m s^{-2}.
- The value of g varies with altitude, depth, shape and the rotation of earth.
- The acceleration due to gravity (g) is related with gravitational constant (G) by the relation

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$$g = \frac{GM_e}{R_e^2} = \frac{G\frac{4}{3}\pi R_e^3 \rho}{R_e^2} = \frac{4}{3}\pi G R_e \rho$$

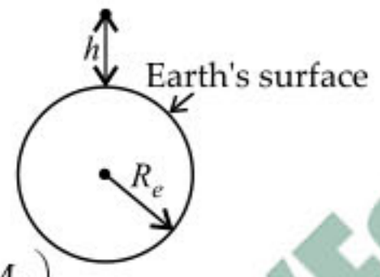
where M_e is the mass of the earth, R_e is the radius of the earth and ρ is the uniform density of the material of the earth.

- The value of acceleration due to gravity is independent of the shape, size, mass etc. of the body but depends upon mass and radius of the earth or planet due to which there is a gravity pull.
- If the radius of a planet decreases by n%, keeping its mass unchanged, the acceleration due to gravity on its surface increases by $2n$%.
- If the mass of a planet increases by n%, keeping its radius unchanged, the acceleration due to gravity on its surface increases by n%.
- If the density of a planet decreases by x%, keeping its radius unchanged, the acceleration due to gravity decreases by x%.

Variation of Acceleration due to Gravity

Due to altitude (h)

The acceleration due to gravity at a height h above the earth's surface is given by



$$g_h = \frac{GM_e}{(R_e + h)^2} = g\left(1 + \frac{h}{R_e}\right)^{-2} \quad \left(\because g = \frac{GM_e}{R_e^2}\right)$$

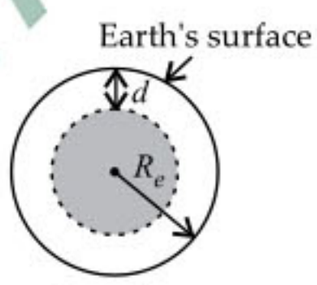
For $h << R_e$

$$\therefore \quad g_h = g\left(1 - \frac{2h}{R_e}\right)$$

Thus, the value of acceleration due to gravity decreases with the increase in height h.

Due to depth (d)

The acceleration due to gravity at a depth d below the earth's surface is given by

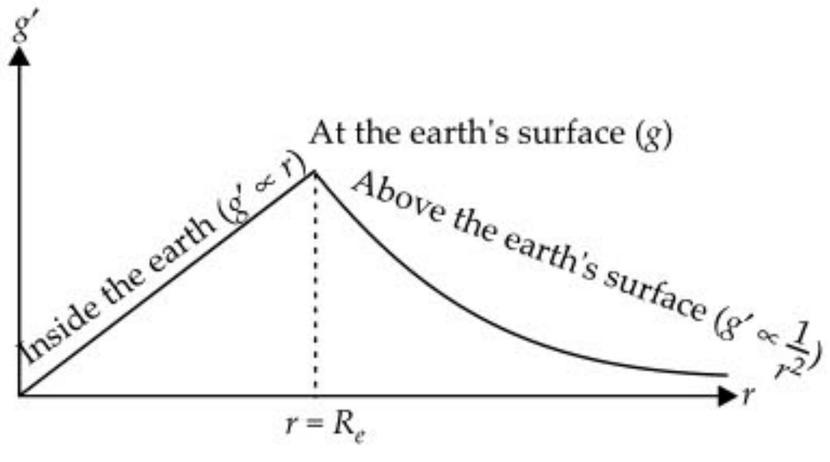


$$g_d = \frac{GM_e}{R_e^2}\left(1 - \frac{d}{R_e}\right) = g\left(1 - \frac{d}{R_e}\right) \qquad \left(\because \quad g = \frac{GM_e}{R_e^2}\right)$$

At the centre of the earth, $d = R_e$. $\therefore \quad g_d = 0$.

Thus, the value of acceleration due to gravity decreases with the increase in depth d and becomes zero at the centre of the earth.

The variation of acceleration due to gravity (g') with distance from the centre of the earth (r) is as shown in the figure.



Due to rotation of the earth about its axis

The acceleration due to gravity at latitude λ is given by

$$g_\lambda = g - R_e \omega^2 \cos^2\lambda$$

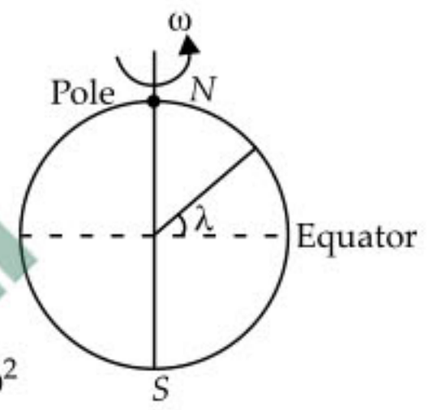
where ω is the angular speed of rotation of the earth about its axis and its value is 7.3×10^{-5} rad s^{-1}.

At equator, $\lambda = 0°$

$$g_{equator} = g - R_e\omega^2\cos^2 0° = g - R_e\omega^2$$

At poles, $\lambda = 90°$

$$g_{pole} = g - R_e\omega^2\cos^2 90° = g$$



Thus, the value of acceleration due to gravity increases from equator to the pole due to rotation of the earth.

$$g_{pole} - g_{equator} = g - (g - R_e\omega^2) = R_e\omega^2$$

If the earth stops rotating about its axis ($\omega = 0$), the value of g will increase everywhere, except at the poles. On the contrary, if there is increase in the angular speed of the earth, then except at the poles the value of g will decrease at all places.

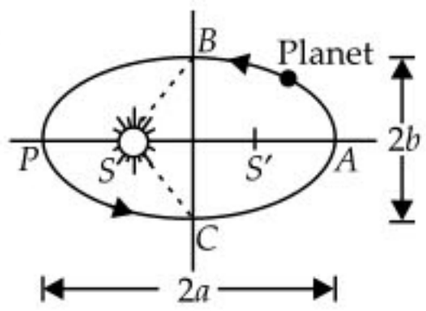
Due to shape of the earth : Earth is not a perfect sphere but it is an ellipsoid. The earth's radius is 21 km larger at the equator than at the poles. Thus, the earth has an equatorial bulge and is flattened at the poles. Both, rotation and equatorial bulge contribute additively to keep the g smaller at the equator than at the poles.

Kepler's laws of planetary motion

To explain the motion of the planets, Kepler formulated the following three laws:

1. Law of orbits (First law)

Each planet revolves around the sun in an elliptical orbit with the sun situated at one of the two foci.



As shown in fig. the planets move around the sun in an elliptical orbit. An ellipse has two foci S and S' the sun remains at one focus S.

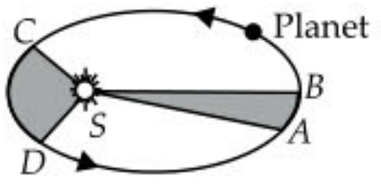
The points P and A on the orbit are called the perihelion and the aphelion and represent the closest and farthest distances from the sun rspectively.

2. Law of areas (Second law)

The radius vector drawn from the sun to the planet sweeps out equal areas in equal intervals of time *i.e.* the areal velocity of the planet (or the area swept out by the planet per unit time) around the sun is constant *i.e.*

$$\text{areal velocity} = \frac{d\vec{A}}{dt} = \text{ a constant, for a planet.}$$

Kepler's second law follows from the law of conservation of angular momentum.



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Suppose a planet takes same time to go from position A to B as in going from C to D. From Kepler's second law, the areas ASB and CSD (covered in equal time) must be equal.

3. Law of periods (Third law)

The square of the time period of revolution of a planet around the sun is directly proportional to the cube of semi major axis of the elliptical orbit.

i.e. $T^2 \propto a^3$

where a is the semi major axis of the elliptical orbit of the planet around the sun. This law is also known as harmonic law.

Gravitational field

It is the space around a material body in which its gravitational pull can be experienced by other bodies.

Intensity of Gravitational Field

The intensity of the gravitational field of a body at a point in the field is defined as the force experienced by a body of unit mass placed at that point provided the presence of unit mass does not disturb the original gravitational field. It is denoted by symbol E.

The intensity of gravitational field at a point due to a body of mass M, at a distance r from the centre of the body is

$$E = \frac{GM}{r^2}$$

The intensity of gravitational field is a vector quantity. Its dimensional formula is $[M^0LT^{-2}]$.

The SI unit of intensity of gravitational field is N kg^{-1} and its CGS unit is dyne g^{-1}.

Gravitational Potential

Gravitational potential at a point in the gravitational field of a body is defined as the amount of work done in bringing body of unit mass from infinity to that point. It is denoted by symbol V.

The gravitational potential at a point in the gravitational field due to a body of mass M at a distance r from the centre of the body is given by

$$V = -\frac{GM}{r}$$

Gravitational potential is a scalar quantity. Its dimensional formula is $[M^0L^2T^{-2}]$.

The SI unit of gravitational potential is J kg^{-1} and its CGS unit is erg g^{-1}.

Gravitational potential (V) is related with gravitational field intensity (E) by a relation

$$E = -\frac{dV}{dr}$$

Gravitational Field Intensity and Gravitational Potential due to a Spherical Shell

The gravitational field intensity and gravitational potential due to a spherical shell of radius R and mass M at a point distant r from the centre of the shell is given as follows:

- At a point outside the shell *i.e.* $r > R$

$$E_{outside} = \frac{GM}{r^2},\ V_{outside} = -\frac{GM}{r}$$

- At a point on the surface of the shell *i.e.* $r = R$

$$E_{surface} = \frac{GM}{R^2},\ V_{surface} = -\frac{GM}{R}$$

- At a point inside the shell *i.e.* $r < R$

$$E_{inside} = 0,\ V_{inside} = -\frac{GM}{R}$$

Gravitational Field Intensity and Gravitational Potential due to a Solid Sphere

The gravitational field intensity and gravitational potential due to a solid sphere of radius R and mass M at a point distant r from the centre of the sphere is given as follows:

- At a point outside the sphere *i.e.* $r > R$

$$E_{outside} = \frac{GM}{r^2},\ V_{outside} = -\frac{GM}{r}$$

- At a point on the surface of the sphere *i.e.* $r = R$

$$E_{surface} = \frac{GM}{R^2},\ V_{surface} = -\frac{GM}{R}$$

- At a point inside the sphere *i.e.* $r < R$

$$E_{inside} = \frac{GMr}{R^3},\ V_{inside} = -\frac{GM(3R^2 - r^2)}{2R^3}$$

Gravitational potential energy

The gravitational potential energy of a body at a point in a gravitational field of another body is defined as the amount of work done in bringing the given body from infinity to that point.

Gravitational potential = Gravitational potential energy × mass of the body

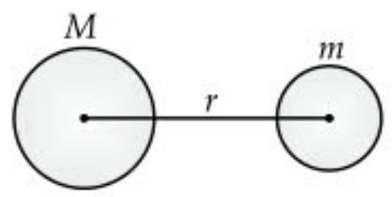
The gravitational potential energy of mass m in the gravitational field of mass M at a distance r from it is

$$U = -\frac{GMm}{r}$$

where, r is the distance between M and m.

The gravitational potential energy of a mass m at a distance r ($> R_e$) from the centre of the earth is

$$U = mV = -\frac{GM_em}{r}$$



Gravitational potential energy of a mass at infinite distance from the earth is zero.

Gravitational potential energy is a scalar quantity. Its dimensional formula is $[ML^2T^{-2}]$ and SI unit is J.

Gravitational potential energy of a body of mass m at a height h above the earth's surface is given by

$$U_h = -\frac{GM_em}{(R_e + h)}$$

Gravitational potential energy of a body of mass m on the earth's surface is given by

$$U_s = -\frac{GM_em}{R_e}$$

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The change in potential energy when a body of mass m is moved vertically upwards through a height h from the earth's surface given by

$$\Delta U = U_h - U_s = GM_e m\left[\frac{1}{R_e} - \frac{1}{R_e + h}\right]$$

$$= \frac{GM_e mh}{R_e^2\left(1+\frac{h}{R_e}\right)} = \frac{mgh}{\left(1+\frac{h}{R_e}\right)} \qquad \left(\because \quad g = \frac{GM_e}{R_e^2}\right)$$

For $h << R_e$, $\Delta U = mgh$.

Escape Velocity

The escape velocity on earth (or any planet) is defined as the minimum velocity with which a body has to be projected vertically upwards from the surface of earth (or any other planet) so that it just crosses the gravitational field of earth (or of that planet) and never returns on its own. Escape velocity v_e is given by

$$v_e = \sqrt{\frac{2GM}{R}}$$

where M = Mass of the earth/planet
R = Radius of the earth/planet

$$v_e = \sqrt{\frac{2G \times \text{volume} \times \text{density}}{R}}$$

or $$v_e = \sqrt{\frac{2G}{R} \times \frac{4}{3}\pi R^3 \rho} = \sqrt{\frac{8\pi\rho G R^2}{3}}$$

The escape velocity depends upon the mass and radius of the earth/planet from the surface of which the body is to be projected.

The escape velocity is independent of the mass and direction of projection of the body from the surface of earth/planet. For earth, $v_e = 11.2 \text{ km s}^{-1}$

For a point close to earth's surface the escape velocity and orbital velocity are related as

$$v_e = \sqrt{2}\, v_o$$

A given planet will have atmosphere if the root mean square speed of molecules in its atmosphere ($i.e., v_{rms} = \sqrt{3RT/M}$) is smaller than the escape velocity for that planet.

Moon has no atmosphere because the rms velocity of gas molecules there, are greater than the escape velocity of moon.

Satellite

Satellite is a natural or artificial body describing orbit around a planet under its gravitational attraction. Moon is a natural satellite while INSAT-1B is an artificial satellite of the earth.

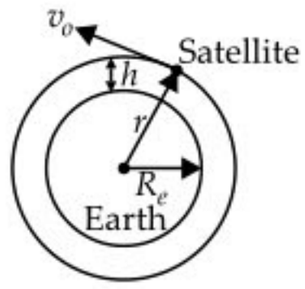
Orbital velocity of a satellite

It is the velocity required to put the satellite into its orbit around the earth.

Orbital velocity of a satellite, revolving around the earth at a height h is given by

$$v_o = \sqrt{\frac{GM_e}{r}} = \sqrt{\frac{GM_e}{R_e + h}}$$

$$= R_e\sqrt{\frac{g}{R_e + h}} \left(\text{As } g = \frac{GM_e}{R_e^2}\right)$$



When the satellite is orbiting close to the earth's surface, *i.e.*, $h << R_e$, then

$$v_o = R_e\sqrt{\frac{g}{R_e}} = \sqrt{gR_e}$$

$$v_o = \sqrt{9.8 \times 6.4 \times 10^6} = 7.92 \times 10^3 \text{ m s}^{-1} \approx 8 \text{ km s}^{-1}$$

The orbital velocity of a satellite is independent of the mass of the satellite but depends upon the mass and radius of the earth/planet around which the revolution of satellite is taking place. The direction of orbital velocity of the satellite at an instant is along the tangent to the orbital path of satellite at that instant.

Time period of a satellite

It is the time taken by satellite to complete one revolution around the earth and it is given by

$$T = \frac{2\pi r}{v_o} = 2\pi\sqrt{\frac{r^3}{GM_e}} = 2\pi\sqrt{\frac{(R_e + h)^3}{GM_e}} = \frac{2\pi}{R_e}\sqrt{\frac{(R_e + h)^3}{g}}$$

For a satellite orbiting close to the earth's surface *i.e.* $h << R_e$

$$T = 2\pi\sqrt{\frac{R_e}{g}} = 2\pi\sqrt{\frac{6.4\times10^6 \text{ m}}{9.8 \text{ m s}^{-2}}} = 5.08\times10^3 \text{ s} = 84.6 \text{ min.}$$

The period of revolution of the satellite depends upon its height above earth's surface. Larger is the height of the satellite, the greater will be its time period of revolution.

Height of satellite above the earth's surface

$$h = \left(\frac{T^2 R_e^2 g}{4\pi^2}\right)^{1/3} - R_e$$

Kinetic energy of a satellite

$$K = \frac{1}{2}mv_o^2 = \frac{1}{2}\frac{GM_e m}{r} = \frac{1}{2}\frac{GM_e m}{(R_e + h)}$$

Potential energy of a satellite

$$U = -\frac{GM_e m}{r} = -\frac{GM_e m}{R_e + h}$$

Total energy (mechanical) of a satellite

$$E = K + U = -\frac{GM_e m}{2r} = -\frac{GM_e m}{2(R_e + h)}$$

For satellite orbiting very close to the surface of earth *i.e.*, $h << R_e$ then $E = -\dfrac{GM_e m}{2R_e}$

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Kinetic energy of a satellite is equal to negative of total energy while potential energy is equal to twice the total energy.

$$i.e.\ K = -E,\ U = 2E$$

Binding energy of a satellite

$$E_B = -E = \frac{GM_e m}{2r} = \frac{GM_e m}{2(R_e + h)}$$

Angular momentum of a satellite

$$L = mv_o r = mr\sqrt{\frac{GM_e}{r}} = [m^2 rGM_e]^{1/2}$$

Angular momentum of a satellite depends on both, mass of the satellite (m) and mass of the earth (M_e). It also depends upon the radius of the orbit (r) of the satellite.

Angular momentum is conserved in the motion of satellite.

Geostationary Satellite

A satellite which revolves around the earth in its equatorial plane with the same angular speed and in the same direction as the earth rotates about its own axis is called a geostationary or synchronous satellite.

The height of a geostationary satellite above the earth's surface is given by

$$h = \left[\frac{T^2 R_e^2 g}{4\pi^2}\right]^{1/3} - R_e$$

Here, $T = 24\text{ h} = 86400\text{ s}$,

$$R_e = 6400\text{ km} = 6.4 \times 10^6\text{ m},\ g = 9.8\text{ m s}^{-2}$$

$$\therefore \quad h = \left[\frac{(86400)^2 \times (6.4\times10^6)^2 \times 9.8}{4 \times (3.14)^2}\right]^{1/3} - 6.4\times10^6$$

$$\approx 3.6 \times 10^7\text{ m} = 36000\text{ km}$$

Geostationary satellites are used for the purpose of communication as they act as reflectors of suitable waves carrying the messages. Therefore, they are also called communication satellites. Telstar was the first communication satellite launched by U.S.A. in 1962. INSAT 2B and INSAT 2C are the communication satellites of India.

Essential Conditions for Geostationary Satellite

These are as follows:

- A geostationary satellite should be at a height nearly 36000 km above the equator of earth.
- Its period of revolution around the earth should be the same as that of the earth about its axis, *i.e.*, exactly 24 hours.
- It should revolve in an orbit concentric and coplanar with the equatorial plane, so the plane of orbit of the satellite is normal to the axis of rotation of the earth.
- Its sense of rotation should be the same as that of the earth about its own axis, *i.e.*, from west to east. Its orbital speed is nearly 3.1 km s^{-1}.

Polar Satellite

A satellite revolves in a polar orbit is called a polar satellite.

A polar orbit is that orbit whose angle of inclination with equatorial plane of earth is 90°. The polar satellites are low altitude satellites. They go around the poles of the earth from north to south direction whereas the earth rotates around its axis from west to east direction.

The altitude of polar satellites is about 500 to 800 km from the earth's surface. The time period of revolution of polar satellites is about 100 minutes.

The polar satellites are used for getting the information about the images of cloud, atmospheric data, ozone layer in the atmosphere and to detect the ozone hole over Antarctica. The information collected through polar satellites is extremely useful for remote sensing, meteorology as well as for environmental studies of the earth.

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EXAM DRILL

1. When a shell travelling along a parabolic path in the gravitational field explodes in the mid air, the centre of mass of fragments will continue to move
(a) vertically down
(b) along the original parabolic path
(c) vertically up and then vertically down
(d) horizontally followed by parabolic path

2. The change in potential energy when a body of mass m is raised to a height nR from earth's surface is (R = radius of the earth)
(a) $mgR\frac{n}{(n-1)}$ (b) mgR
(c) $mgR\frac{n}{(n+1)}$ (d) $\frac{mgR}{n}$

3. A satellite is orbiting around the earth with kinetic energy K. What will happen if the satellite's kinetic energy is made $2K$?
(a) Radius of the orbit is doubled
(b) Radius of the orbit is halved
(c) Period of revolution is doubled
(d) Satellite escapes away

4. A geostationary satellite is orbiting the earth at a height of $5R$ above that surface of the earth, R being the radius of the earth. The time period of another satellite in hours at a height of $2R$ from the surface of the earth is
(a) 5 (b) 10 (c) $6\sqrt{2}$ (d) $\frac{6}{\sqrt{2}}$

5. Three uniform spheres of mass M and radius R each are kept in such a way that each touches the other two. The magnitude of gravitational force on any of the spheres due to other two is
(a) $\frac{\sqrt{3}\,GM^2}{2R^2}$ (b) $\frac{3}{2}\frac{GM^2}{R^2}$
(c) $\frac{\sqrt{3}GM^2}{R^2}$ (d) $\frac{\sqrt{3}}{4}\frac{GM^2}{R^2}$

6. A particle of mass M is situated at the centre of a spherical shell of same mass and radius a. The gravitational potential at a point situated at $\frac{a}{2}$ distance from the centre, will be
(a) $-\frac{3GM}{a}$ (b) $-\frac{2GM}{a}$ (c) $-\frac{GM}{a}$ (d) $-\frac{4GM}{a}$

7. The acceleration due to gravity on the moon is one-sixth that of the earth. If the earth and moon are assumed to have the same density, the ratio of the radii of moon and earth will be
(a) $\frac{1}{6}$ (b) $\frac{1}{(6)^{1/3}}$ (c) $\frac{1}{36}$ (d) $\frac{1}{(6)^{2/3}}$

8. The tidal wave in the sea are primarily due to gravitational effect of
(a) earth on the sea (b) sun on the earth
(c) earth on the moon (d) moon on the earth

9. A uniform sphere of mass m and radius R is placed on a rough horizontal surface. The sphere is struck horizontally at a height h from the floor. The sphere rolls without slipping with a constant velocity, when h
(a) $\frac{2}{5}R$ (b) $\frac{5}{7}R$ (c) $\frac{7}{5}R$ (d) $\frac{5}{2}R$

10. Two particles of equal mass have coordinates (2 m, 4 m, 6 m) and (6 m, 2 m, 8 m). Of these one particle has a velocity $\vec{v}_1 = (2\hat{i})$ m s^{-1} and another particle has velocity $\vec{v}_2 = (2\hat{j})$ m s^{-1} at time t = 0. The coordinate of their centre of mass at time t = 1 s will be
(a) (4 m, 4 m, 7 m) (b) (5 m, 4 m, 7 m)
(c) (2 m, 4 m, 6 m) (d) (4 m, 5 m, 4 m)

11. A satellite is moving in a circular orbit at a certain height above the earth's surface. It takes 5.26×10^3 s to complete one revolution with a centripetal acceleration equal to 9.32 m s^{-2}. The height of the satellite orbit above the earth's surface is (Radius of earth = 6.37×10^6 m)
(a) 70 km (b) 160 km (c) 190 km (d) 220 km

12. A synchronous satellite goes around the earth once in every 24 h. What is the radius of orbit of the synchronous satellite in terms of the earth's radius? (Given mass of the earth, $M_e = 5.98 \times 10^{24}$ kg, radius of the earth, $R_e = 6.37 \times 10^6$ m, Universal constant of gravitation, $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}).
(a) 2.4 Re (b) 3.6 Re (c) 4.8 R_e (d) 6.6 R_e

13. A particle of mass M is situated at the centre of a spherical shell of same mass and radius a. The gravitational potential at a point situated at distance $\frac{a}{2}$ from the centre, will be
(a) $-\frac{3GM}{a}$ (b) $-\frac{2GM}{a}$ (c) $-\frac{GM}{a}$ (d) $-\frac{4GM}{a}$

14. In the solar system, sun is in the focus of system for sun-earth binding system. Then the binding energy for the system will be
(Given that the radius of the earth orbit round the sun is 1.5×10^{11} m, mass of earth is 6×10^{24} kg, mass of sun is 10^{30} kg)
(a) 2.7×10^{33} J (b) 1.3×10^{33} J
(c) 2.7×10^{30} J (d) 1.3×10^{30} J

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15. A saturn year is 29.5 times the earth year. How far is the saturn from the sun if the earth is 1.5×10^8 km away from the sun?
(a) 1.2×10^9 km (b) 1.3×10^9 km
(c) 1.4×10^9 km (d) 1.5×10^9 km

16. The acceleration due to gravity on the surface of moon is 1.7 m s^{-2}. What is the time period of a simple pendulum on the surface of moon if its time period on the surface of earth is 3.5 s? (g on the surface of earth is 9.8 m s^{-2})
(a) 6.4 s (b) 7.4 s (c) 8.4 s (d) 9.4 s

17. The maximum vertical distance through which a full dressed astronaut can jump on the earth is 0.5 m. Estimate the maximum vertical distance through which he can jump on the moon, which has a mean density 2/3rd that of earth and radius one quarter that of the earth.
(a) 1.5 m (b) 3 m (c) 6 m (d) 7.5 m

18. The escape velocity for a planet is v_e. A tunnel is dug along a diameter of the planet and a small body is dropped into it at the surface. When the body reaches the centre of the planet, its speed will be
(a) v_e (b) $\frac{v_e}{\sqrt{2}}$ (c) $\frac{v_e}{2}$ (d) zero

19. An asteroid of mass m is approaching earth, initially at a distance of $10R_e$ from the centre of the earth with speed v_i. It hits the earth with a speed v_f (R_e and M_e are radius and mass of the earth), then
(a) $v_f^2 = v_i^2 + \frac{2Gm}{M_eR_e}\left(1-\frac{1}{10}\right)$
(b) $v_f^2 = v_i^2 + \frac{2GM_e}{R_e}\left(1+\frac{1}{10}\right)$
(c) $v_f^2 = v_i^2 + \frac{2GM_e}{R_e}\left(1-\frac{1}{10}\right)$
(d) $v_f^2 = v_i^2 + \frac{2Gm}{R_e}\left(1-\frac{1}{10}\right)$

20. For a satellite moving in an orbit around the earth, the ratio of kinetic energy to magnitude of potential energy is
(a) $\frac{1}{\sqrt{2}}$ (b) 2 (c) $\sqrt{2}$ (d) $\frac{1}{2}$

21. Two satellites of masses m_1 and m_2 ($m_1 > m_2$) are revolving around the earth in a circular orbit of radii r_1 and r_2 ($r_1 > r_2$) respectively. Which of the following statements is true regarding their speeds v_1 and v_2?
(a) $v_1 = v_2$ (b) $v_1 > v_2$ (c) $v_1 < v_2$ (d) $\frac{v_1}{r_1} = \frac{v_2}{r_2}$

22. The radius of a planet is R_1 and a satellite revolves around it in a circular orbit of radius R_2. The time period of revolution is T. What is the acceleration due to gravity on the surface of the planet?
(a) $\frac{4\pi^2R_2^3}{T^2R_1^2}$ (b) $\frac{4\pi^2R_2^2}{T^2R_1^3}$ (c) $\frac{4\pi^2R_2^2}{T^2}$ (d) $\frac{4\pi^2R_2^2}{T^2R_1^2}$

23. If a satellite of mass m is revolving around the earth with distance r from centre, then total energy is
(a) $-\frac{GMm}{r}$ (b) $-\frac{2GMm}{r}$
(c) $-\frac{GMm}{2r}$ (d) $+\frac{GMm}{2r}$

24. Which of the following Kepler's laws is also known as harmonic law?
(a) First law (b) Second law
(c) Third law (d) None of these

25. The escape velocity for the earth is $v_{es(e)}$. The escape velocity for a planet whose radius is four times and density is nine times that of the earth is
(a) $36v_{es(e)}$ (b) $12v_{es(e)}$ (c) $6v_{es(e)}$ (d) $20v_{es(e)}$

26. Two satellites of earth, S_1 and S_2 are moving in the same orbit. The mass of S_1 is four times the mass of S_2. Which one of the following statements is true?
(a) The potential energies of earth and satellite in the two cases are equal.
(b) S_1 and S_2 are moving with the same speed.
(c) The kinetic energies of the two satellites are equal.
(d) The time period of S_1 is four times that of S_2.

27. The escape velocity of a body from the surface of earth is 11.2 km s^{-1}. A body is projected with a velocity of 22.4 km s^{-1}. Velocity of body at infinite distance from centre of earth would be
(a) 11.2 km s^{-1} (b) zero
(c) $11.2\sqrt{3}$ km s^{-1} (d) $11.\sqrt{2}$ km s^{-1}

28. The potential energy of gravitational interaction of a point mass m and a thin uniform rod of mass M and length l, if they are located along a straight line at distance a from each other is
(a) $U = \frac{GMm}{l}\ln\left(\frac{a+l}{a}\right)$
(b) $U = GMm\left(\frac{1}{a}-\frac{1}{a+l}\right)$
(c) $U = -\frac{GMm}{l}\ln\left(\frac{a+l}{a}\right)$
(d) $U = -\frac{GMm}{a}$

29. At what height h above the earth surface, the value of g becomes $g/2$? (where R is the radius of the earth)
(a) $(\sqrt{2}-1)R$ (b) $\sqrt{2}R$
(c) $(\sqrt{2}+1)R$ (d) $R\sqrt{2}$

30. If r denotes the distance between the sun and the earth, then the angular momentum of the earth around the sun is proportional to

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(a) $r^{3/2}$ (b) r (c) $\sqrt{r}$ (d) r^2

31. Four particles each of mass M, are located at the vertices of a square with side L. The gravitational potential due to this at the centre of the square is

(a) $-\sqrt{32}\,\frac{GM}{L}$ (b) $-\sqrt{64}\,\frac{GM}{L^2}$

(c) zero (d) $\sqrt{32}\,\frac{GM}{L}$

32. By what percent the energy of a satellite has to be increased to shift it from an orbit of radius r to $\frac{3}{2}r$?

(a) 15% (b) 20.3% (c) 66.7% (d) 33.33%

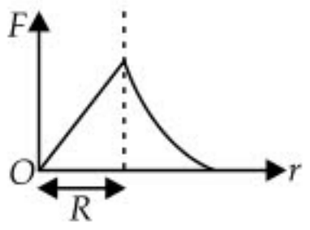
33. The height at which the weight of a body becomes $\frac{1}{16}^{\text{th}}$, its weight on the surface of earth (radius R), is

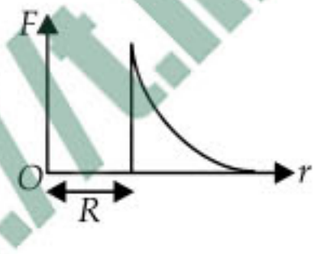
(a) $5R$ (b) $15R$ (c) $3R$ (d) $4R$

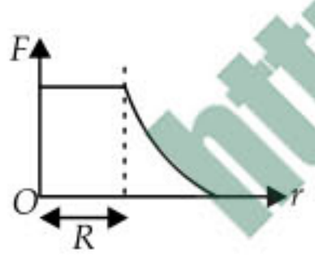
34. The gravitational potential difference between the surface of a planet and a point 20 m above it is 14 J kg^{-1}. The work done in moving a 2.0 kg mass by 8.0 m on a slope of 60° from the horizontal is

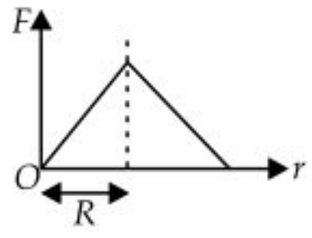
(a) 7 J (b) 9.6 J (c) 16 J (d) 32 J

35. Which one of the following plots represents the variation of gravitational field on a particle with distance r due to a thin spherical shell of radius R? (r is measured from the centre of the spherical shell)

(a) 

(b) 

(c) 

(d) 

36. A body is projected vertically upward from the surface of the earth with a velocity equal to half the escape velocity. If R is radius of the earth, the maximum height attained by the body is

(a) $\frac{R}{6}$ (b) $\frac{R}{3}$ (c) $\frac{2}{3}R$ (d) R

37. Taking the radius of the earth to be 6400 km, by what percentage will the acceleration due to gravity at a height of 100 km from the surface of the earth differ from that on the surface of the earth?

(a) about 1.5% (b) about 5%
(c) about 8% (d) about 3%

38. The acceleration due to gravity at a height $\left(\frac{1}{20}\right)^{\text{th}}$ of the radius of the earth above the earth surface is 9 m s^{-2}. Its value at a point at an equal distance below the surface of the earth in m s^{-2} is about

(a) 8.5 (b) 9.5 (c) 10.5 (d) 11.5

39. A body is projected up with a velocity equal to $\left(\frac{3}{4}\right)^{\text{th}}$ of the escape velocity from the surface of the earth. The height it reaches is (Radius of the earth = R)

(a) $\frac{10}{9}R$ (b) $\frac{9}{7}R$ (c) $\frac{9}{8}R$ (d) $\frac{10}{3}R$

40. The satellite of mass m revolving in a circular orbit of radius r around the earth has kinetic energy K. Then its angular momentum will be

(a) $\sqrt{\frac{K}{mr^2}}$ (b) $\frac{K}{2mr^2}$

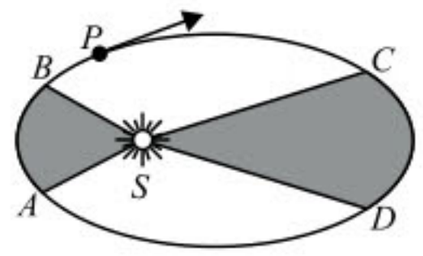
(c) $\sqrt{2Kmr^2}$ (d) $\sqrt{\frac{K}{2mr^2}}$

41. Two bodies of masses m_1 and m_2 are initially at rest infinite distance apart. They are then allowed to move towards each other under mutual gravitational attraction. Their relative velocity of approach at a separation distance r between them is

(a) $\sqrt{\frac{2G(m_1+m_2)}{r}}$ (b) $\sqrt{\frac{2Gm_1m_2}{(m_1+m_2)r}}$

(c) $\sqrt{\frac{G(m_1+m_2)}{r}}$ (d) $\sqrt{\frac{Gm_1m_2}{(m_1+m_2)r}}$

42. Figure shows elliptical orbit of a planet P about the sun S. The shaded area SCD is twice the shaded area SAB. If t_1 is the time for the planet to move from C to D and t_2 is the time to move from A to B, then

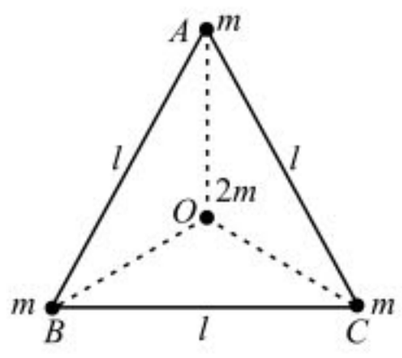


(a) $t_1 = t_2$ (b) $t_1 = 2t_2$
(c) $t_1 = 4t_2$ (d) $t_1 > t_2$

43. If a graph is plotted between T^2 and r^3 for a planet, then its slope will be (where M_S is the mass of the sun)

(a) $\frac{4\pi^2}{GM_S}$ (b) $\frac{GM_S}{4\pi}$ (c) $4\pi GM_S$ (d) GM_S

44. Three masses each of mass m are placed at the vertices of an equilateral triangle ABC of side l as shown in figure. The force acting on a mass $2m$ placed at the centroid O of the triangle is



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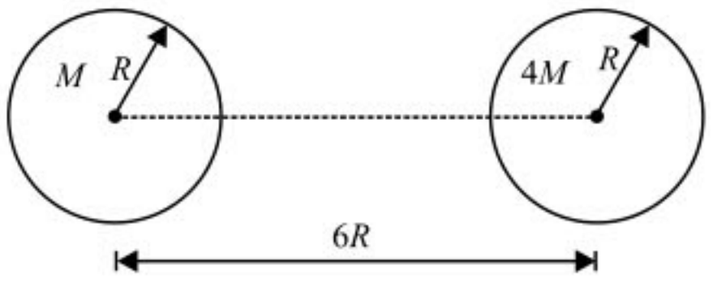
(a) zero (b) $\frac{2Gm^2}{l^2}$ (b) $\frac{4Gm^2}{l^2}$ (d) $\frac{6Gm^2}{l^2}$

45. Two uniform solid spheres of equal radii R, but mass M and $4M$ have a centre to centre separation $6R$, as shown in figure. A projectile of mass m is projected from the surface of the sphere of mass M directly towards the centre of the second sphere. The minimum speed of the projectile so that it reaches the surface of the second sphere is



(a) $\sqrt{\frac{4}{5}\frac{GM}{R}}$ (b) $\sqrt{\frac{5}{4}\frac{GM}{R}}$

(c) $\sqrt{\frac{3}{5}\frac{GM}{R}}$ (d) $\sqrt{\frac{5}{3}\frac{GM}{R}}$

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DAY 07 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ

Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____

(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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1. (b)

2. (c) : Potential energy of a body of mass m on the earth's surface is

$$U_1 = -\frac{GMm}{R}$$

where M is the mass and R is the radius of the body respectively.

Potential energy of the body at height h above the earth's surface is

$$U_2 = -\frac{GMm}{(R+h)} = -\frac{GMm}{(R+nR)} \qquad (\because \quad h = nR)$$

Change in potential energy,

$$\Delta U = U_2 - U_1$$

$$\Delta U = -\frac{GMm}{(R+nR)} - \left(-\frac{GMm}{R}\right)$$

$$= -\frac{GMm}{(R+nR)} + \frac{GMm}{R}$$

$$= \frac{GMm}{R}\left[1 - \frac{1}{(1+n)}\right]$$

$$= \frac{GMm}{R}\left(\frac{n}{(n+1)}\right) = mgR\left(\frac{n}{n+1}\right) \quad \left(\because \quad g = \frac{GM}{R^2}\right)$$

3. (d) : Kinetic energy of the satellite orbiting the earth is $K = \frac{1}{2} m v_o^2$, where v_o is the orbital velocity.

If v_o' is the new velocity when kinetic energy of the satellite becomes double, then

$$\frac{1}{2} m v_o'^2 = 2K = 2 \times \frac{1}{2} m v_o^2 = \frac{1}{2} m (\sqrt{2} v_o)^2$$

$$\therefore \quad v_o' = \sqrt{2}\, v_o$$

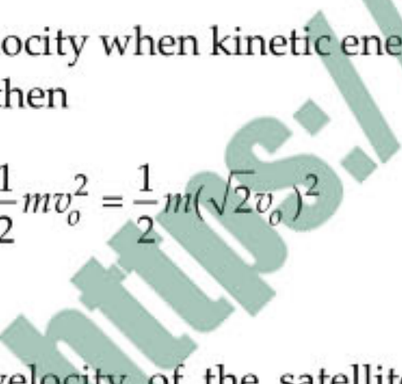
It is the escape velocity of the satellite from the earth. Therefore the satellite will escape away when its kinetic energy is made $2K$.

4. (c) : According to Kepler's third law $T^2 \propto r^3$

$$\therefore \quad \frac{T_2}{T_1} = \left(\frac{r_2}{r_1}\right)^{3/2} = \left(\frac{R+2R}{R+5R}\right)^{3/2} = \left(\frac{3}{6}\right)^{3/2} = \frac{1}{2^{3/2}}$$

$$\frac{T_2}{24} = \frac{1}{2^{3/2}} \quad \text{or} \quad T_2 = \frac{24}{2^{3/2}} = \frac{24}{2\sqrt{2}} = 6\sqrt{2} \text{ hours}$$

5. (d) : The situation is as shown in the figure.



Gravitational force on sphere C due to sphere A is

$$F_{CA} = \frac{GM \times M}{(2R)^2} = \frac{GM^2}{4R^2} \text{ along } CA$$

Gravitational force on sphere C due to sphere B is

$$F_{CB} = \frac{GM \times M}{(2R)^2} = \frac{GM^2}{4R^2} \text{ along } CB$$

These two forces are equal in magnitude and inclined at an angle 60°.

$\therefore$ The total gravitational force on sphere C due to other two spheres is

$$F_{\text{total}} = \sqrt{F_{CA}^2 + F_{CB}^2 + 2F_{CA}F_{CB}\cos 60°}$$

$$= \sqrt{\left(\frac{GM^2}{4R^2}\right)^2 + \left(\frac{GM^2}{4R^2}\right)^2 + 2\left(\frac{GM^2}{4R^2}\right)\left(\frac{GM^2}{4R^2}\right)\left(\frac{1}{2}\right)}$$

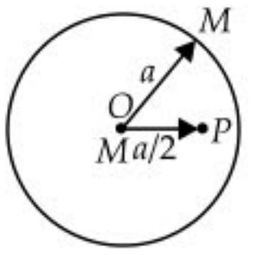
$$= \frac{\sqrt{3}GM^2}{4R^2}$$

6. (a) : Here, mass of a particle = M

Mass of a spherical shell = M

Radius of a spherical shell = a

Point P is at a distance $\frac{a}{2}$ from the centre of the shell as shown in figure.



Gravitational potential at point P due to particle at O is

$$V_1 = -\frac{GM}{(a/2)}$$

Gravitational potential at point P due to spherical shell is

$$V_2 = -\frac{GM}{a}$$

Hence, total gravitational potential at the point P is

$$V = V_1 + V_2$$

$$= -\frac{GM}{(a/2)} + \left(-\frac{GM}{a}\right) = -\frac{2GM}{a} - \frac{GM}{a}$$

$$= -\frac{3GM}{a}$$

7. (a) : $\frac{g_m}{g_e} = \frac{1}{6}$ (Given)

where subscripts m and e refer to moon and earth respectively.

$$\frac{g_m}{g_e} = \frac{\frac{GM_m}{R_m^2}}{\frac{GM_e}{R_e^2}} = \frac{\frac{G}{R_m^2}\rho_m \frac{4}{3}\pi R_m^3}{\frac{G}{R_e^2}\rho_e \frac{4}{3}\pi R_e^3} = \frac{\rho_m R_m}{\rho_e R_e}$$

$$= \frac{R_m}{R_e} \qquad (\because \ \rho_m = \rho_e \text{ (Given)})$$

or $$\frac{R_m}{R_e} = \frac{g_m}{g_e} = \frac{1}{6}$$

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8. (d) : The tidal wave in sea is due to gravitational pull of moon on the earth.

9. (c) : The sphere will roll without slipping with constant velocity when $\omega = \frac{v}{R}$.

Angular momentum of sphere about centre of mass is

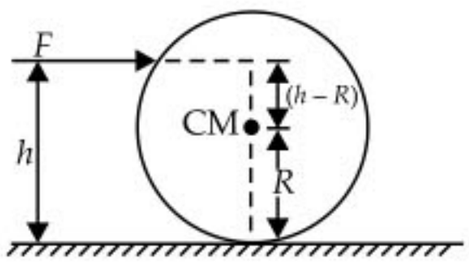
$$mv(h-R) = I\omega = \left(\frac{2}{5}mR^2\right)\left(\frac{v}{R}\right)$$

($\because$ For a sphere $I = \frac{2}{5}\ mR^2$)

$$mv(h-R) = \frac{2}{5}\ mvR$$

$$h - R = \frac{2}{5}R$$

$$h = \frac{2}{5}\ R + R = \frac{7}{5}R$$



10. (b) : After 1 s, coordinates of first particle will become (4 m, 4 m, 6 m) and coordinates of second particle will become (6 m, 4 m, 8 m).

$$\therefore \quad X_{CM} = \frac{4+6}{2} = 5 \text{ m}$$

$$Y_{CM} = \frac{4+4}{2} = 4 \text{ m}$$

$$\text{and } Z_{CM} = \frac{6+8}{2} = 7 \text{ m}$$

11. (b) : As, $T = 2\pi\sqrt{\frac{(R+h)^3}{GM}}$

or $\quad \frac{T^2}{4\pi^2} = \frac{(R+h)^3}{GM} \qquad ...(i)$

Centripetal acceleration, $a = \frac{GM}{(R+h)^2}$

or $\quad \frac{(R+h)^2}{GM} = \frac{1}{a} \qquad ...(ii)$

Divide (i) by (ii), we get

$$(R+h) = \frac{T^2}{4\pi^2} \times a = \left(\frac{5.26 \times 10^3}{2\pi}\right)^2 \times 9.32$$

$R + h = 6.53 \times 10^6$ m

$h = 6.53 \times 10^6 \text{ m} - 6.37 \times 10^6 \text{ m} = 0.16 \times 10^6 \text{ m}$

$= 160 \times 10^3 \text{ m} = 160 \text{ km}$

12. (d) : Time period of satellite

$$T = 2\pi\sqrt{\frac{R^3}{GM_e}}$$

Also, $\quad g = \frac{GM_e}{R_e^2} \qquad ...(i)$

$\therefore \quad T^2 = \frac{4\pi^2 R^3}{gR_e^2}$ (Using (i))

Substituting the given values in above equation, we get

$$(24 \times 60 \times 60)^2 = \frac{4 \times (3.14)^2 R^3}{9.8 R_e^2}$$

or $\quad R = 6.6R_e$

13. (a) : Gravitational potential due to the shell at any point inside it $= -\frac{GM}{a}$

Gravitational potential due to the particle at the centre at a point P distant $\frac{a}{2}$ from the centre

$$= -\frac{GM}{a/2} = -\frac{2GM}{a}$$

$\therefore$ Net gravitational potential at P

$$= -\frac{GM}{a} - \frac{2GM}{a} = -\frac{3GM}{a}$$

14. (b) : Binding energy $= \frac{GMm}{2R}$

Mass of sun, $M = 10^{30}$ kg

Mass of earth, $m = 6 \times 10^{24}$ kg

$R = 1.5 \times 10^{11}$ m

Binding energy of the system

$$= \frac{6.67 \times 10^{-11} \times 10^{30} \times 6 \times 10^{24}}{2 \times 1.5 \times 10^{11}} = 1.3 \times 10^{33} \text{ J}$$

15. (c) : Here, $T_s = 29.5\ T_e$; $R_e = 1.5 \times 10^8$ km;

According to Kepler's third law, $T^2 \propto R^3$

$$\therefore \quad \frac{T_s^2}{T_e^2} = \frac{R_s^3}{R_e^3} \quad \text{or} \quad R_s = R_e\left(\frac{T_s}{T_e}\right)^{2/3}$$

$$R_s = 1.5 \times 10^8 \left(\frac{29.5\ T_e}{T_e}\right)^{2/3} = 1.4 \times 10^9 \text{ km}$$

16. (c) : Here, $g_m = 1.7$ m s^{-2}; $g_e = 9.8$ m s^{-2}; $T_e = 3.5$ s

As $\quad T_e = 2\pi\sqrt{\frac{l}{g_e}}$ and $\quad T_m = 2\pi\sqrt{\frac{l}{g_m}}$

$$\therefore \quad \frac{T_m}{T_e} = \sqrt{\frac{g_e}{g_m}} \quad \text{or} \quad T_m = T_e\sqrt{\frac{g_e}{g_m}} = 3.5\sqrt{\frac{9.8}{1.7}} = 8.4 \text{ s}$$

17. (b) : Energy spent $= mg_eh_e = mg_mh_m$

$$\text{or} \quad h_m = \frac{g_eh_e}{g_m} = \frac{\left(G\frac{4}{3}\pi R_e^3\rho_e / R_e^2\right)h_e}{\left(G\frac{4}{3}\pi R_m^3\rho_m / R_m^2\right)}$$

$$= \frac{R_e}{R_m} \times \frac{\rho_e}{\rho_m} \times h_e = \frac{3}{2} \times \frac{4}{1} \times 0.5 = 3 \text{ m}$$

18. (b) : As $v_e = \sqrt{2Rg}$

At the surface of the planet, $V_s = -\frac{GM}{R}$

At the centre of the planet, $V_c = -\frac{3GM}{2R}$

$$\frac{1}{2}mv^2 = m(V_s - V_c]$$

or $\quad v^2 = 2\frac{GM}{R}\left(\frac{3}{2} - 1\right) = \frac{GM}{R} = Rg = \frac{v_e^2}{2}$ or $v = \frac{v_e}{\sqrt{2}}$

19. (c) : According to law of conservation of mechanical energy, we get

$$\frac{1}{2}mv_i^2 - \frac{GM_em}{10R_e} = \frac{1}{2}mv_f^2 - \frac{GM_em}{R_e}$$

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$$v_i^2 - \frac{2GM_e}{10R_e} = v_f^2 - \frac{2GM_e}{R_e}$$

$$v_f^2 = v_i^2 - \frac{2GM_e}{10R_e} + \frac{2GM_e}{R_e}$$

$$v_f^2 = v_i^2 + \frac{2GM_e}{R_e}\left(1 - \frac{1}{10}\right)$$

20. (d) $\text{K.E.} = \frac{1}{2}mv_0^2$

$$= \frac{1}{2}m\left(\sqrt{\frac{GM}{r}}\right)^2 = \frac{GMm}{2r} \quad \left(\because \quad v_0 = \sqrt{\frac{GM}{r}}\right)$$

$$\text{P.E.} = -\frac{GMm}{r}$$

$$|\text{P.E.}| = \frac{GMm}{r} \quad \therefore \quad \frac{\text{K.E.}}{|\text{P.E.}|} = \frac{1}{2}$$

21. (c) : A satellite of mass m revolving around the earth in a circular orbit of radius r with speed v given by

$v = \sqrt{\frac{GM_E}{r}}$ where M_E is the mass of the earth.

It does not depend upon the mass of the satellite.

$$v \propto \frac{1}{\sqrt{r}} \quad \therefore \quad \frac{v_1}{v_2} = \sqrt{\frac{r_2}{r_1}}$$

As $r_1 > r_2$

$$\therefore \quad \frac{v_1}{v_2} < 1 \text{ or } v_1 < v_2$$

22. (a) : Time period of satellite around the planet is given by

$$T^2 = \frac{4\pi^2}{GM_P} \times R_2^3$$

$$\therefore \quad GM_P = \frac{4\pi^2}{T^2} \times R_2^3 \qquad ...(i)$$

Let g is the acceleration due to gravity on the surface of the planet,

$$\therefore \quad g = \frac{GM_P}{R_1^2} \qquad ...(ii)$$

From (i) and (ii), we get

$$g = \frac{4\pi^2}{T^2}\frac{R_2^3}{R_1^2}$$

23. (c) : The satellite revolving around the earth has two types of energies.

(i) Gravitational potential energy U due to position of the satellite is given by

$$U = -\frac{GMm}{r}$$

(ii) Kinetic energy K due to orbital velocity of satellite is given by

$$K = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{GM}{r}\right) = \frac{GMm}{2r} \qquad \left(\because v = \sqrt{\frac{Gm}{r}}\right)$$

$$\therefore \quad \text{Total energy} = U + K = -\frac{GMm}{r} + \frac{GMm}{2r}$$

$$= -\frac{GMm}{2r}$$

24. (c) : Kepler's third law is also known as harmonic law.

25. (b) : The escape velocity for the surface of earth is

$$v_{es(e)} = \sqrt{\frac{2GM_e}{R_e}}$$

where M_e and R_e is the mass and radius of the earth respectively.

or $\quad v_{es(e)} = R_e\sqrt{\frac{8}{3}G\pi\rho} \qquad \left[\because M_e = \frac{4}{3}\pi R_e^3\,\rho\right]$

$$= R_e\sqrt{\frac{8}{3}G\pi\rho}$$

$$v_{es(p)} = 4R\sqrt{\frac{8}{3}G\pi 9\rho} \qquad \left(\because \rho_p = 9\rho, R_p = 4R_e\right)$$

$$\therefore \quad \frac{v_{es(e)}}{v_{es(p)}} = \frac{R_e\sqrt{\frac{8}{3}G\pi\rho}}{4R_e\sqrt{\frac{8}{3}G\pi 9\rho}} = \frac{1}{12}$$

or, $\quad v_{es(p)} = 12v_{es(e)}$

26. (b) : Both, orbital speed of satellite $(v_o = \sqrt{GM_e/r})$ and time period of revolution of satellite, $T = \left[\frac{4\pi^2 r^3}{GM_e}\right]^{1/2}$ are independent of mass of satellite. Therefore orbital speed and time period of revolution of both the satellites are same.

Hence option (b) is correct.

The kinetic energy of a satellite, $K = \frac{GM_e m}{2r}$ and potential energy of a satellite, $U = -\frac{GM_e m}{r}$ both depend on mass of satellite.

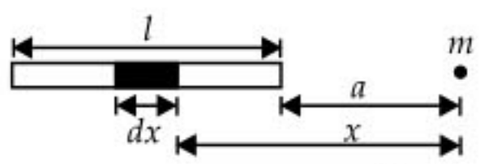
27. (c) : If v is the velocity of the body at infinite distance from the centre of the earth and u is the velocity of projection of body, then

$$\frac{1}{2}mu^2 = \frac{1}{2}mv_e^2 + \frac{1}{2}mv^2$$

$$v^2 = u^2 - v_e^2$$

or $\quad v = \sqrt{u^2 - v_e^2} = \sqrt{(22.4)^2 - (11.2)^2} = 11.2\sqrt{3}\ \text{km s}^{-1}$

28. (c) :



Mass per unit length of rod $= \frac{M}{l}$

Mass of element of length dx, $dm = \frac{M}{l}dx$

The gravitational potential energy between this element and point mass is

$$dU = -\frac{Gmdm}{x} = -\frac{Gm\left(\frac{M}{l}dx\right)}{x}$$

$$\therefore \quad U = -\frac{GmM}{l}\int_a^{a+l}\frac{dx}{x} \quad \text{or} \quad U = -\frac{GmM}{l}\ln\left(\frac{a+l}{a}\right)$$

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29. (a) : As $g' = g\left(\frac{R}{R+h}\right)^2$

Given : $g' = \frac{g}{2}$

or $\frac{g}{2} = g\left(\frac{R}{R+h}\right)^2$ or $\frac{1}{2} = \left(\frac{R}{R+h}\right)^2$

or $\frac{1}{\sqrt{2}} = \frac{R}{R+h}$

or $R\sqrt{2} = (R+h)$ $\therefore$ $h = R(\sqrt{2}-1)$

30. (c) : Angular momentum of the earth around the sun is

$L = M_e v_o r$

$= M_e\sqrt{\frac{GM_s}{r}}\, r$ $\left(\because \quad v_o = \sqrt{\frac{GM_s}{r}}\right)$

$\therefore \quad L = \left[M_e^2 GM_s r\right]^{1/2}$

where, M_e = mass of the earth

M_s = mass of the sun

r = distance between the sun and the earth

$\therefore \quad L \propto \sqrt{r}$

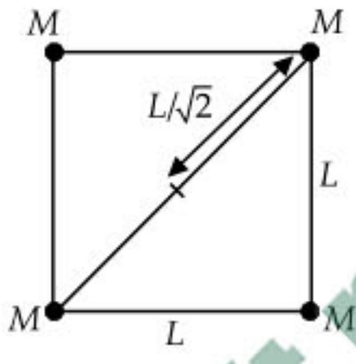
31. (a) : Gravitational potential at the centre is

$U = -4\left(\frac{GM}{L/\sqrt{2}}\right)$

$= -\frac{4\sqrt{2}\,GM}{L}$

$= -\sqrt{2\times 16}\,\frac{GM}{L}$

$= -\sqrt{32}\,\frac{GM}{L}$



32. (d)

33. (c) : Acceleration due to gravity at a height h from the surface of earth is

$$g' = \frac{g}{\left(1+\frac{h}{R}\right)^2} \qquad \text{....(i)}$$

where g is the acceleration due to gravity at the surface of earth and R is the radius of earth.

Multiplying by m (mass of the body) on both sides in (i), we get

$$mg' = \frac{mg}{\left(1+\frac{h}{R}\right)^2}$$

$\therefore$ Weight of body at height h, $W' = mg'$

Weight of body at surface of earth, $W = mg$

According to question, $W' = \frac{1}{16}W$

$\therefore \quad \frac{1}{16} = \frac{1}{\left(1+\frac{h}{R}\right)^2}$

$\left(1+\frac{h}{R}\right)^2 = 16$ or $1+\frac{h}{R} = 4$ or $\frac{h}{R} = 3$ or $h = 3R$

34. (b) : Gravitational intensity,

$I = \frac{dV}{dx} = \frac{14}{20} = 0.7 \text{ N kg}^{-1}$

Acceleration due to gravity,

$g = I = 0.7 \text{ N kg}^{-1}$

Work done under this field in displacing a body on a slope of 60° through a distances

$= m(g\sin 60°)\, s$

$= 2\times\left(0.7\times\frac{\sqrt{3}}{2}\right) 8 = 9.6 \text{ J}$

35. (b) : Gravitational field due to the thin spherical shell

Inside the shell,

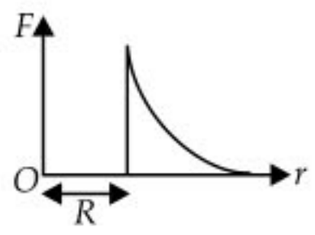
$F = 0$ (For $r < R$)

On the surface of the shell,

$F = \frac{GM}{R^2}$ (For $r = R$)

Outside the shell,

$F = \frac{GM}{r^2}$ (For $r > R$)



The variation of F with distance r from the centre is as shown in the adjacent figure.

36. (b) : Let a body is projected from the surface of the earth with the velocity v and reaches maximum height h. According to law of conservation of mechanical energy, we get

$\frac{1}{2}mv^2 - \frac{GMm}{R} = 0 - \frac{GMm}{(R+h)}$

or $\frac{1}{2}v^2 - \frac{GM}{R} = -\frac{GM}{(R+h)}$

As per question,

$v = \frac{v_e}{2} = \frac{1}{2}\sqrt{\frac{2GM}{R}}$ $\left[\because \quad v_e = \sqrt{\frac{2GM}{R}}\right]$

$\frac{1}{2}\left(\frac{1}{2}\frac{GM}{R}\right) - \frac{GM}{R} = -\frac{GM}{(R+h)}$

$\frac{GM}{4R} - \frac{GM}{R} = -\frac{GM}{R+h}$

$-\frac{3}{4R} = -\frac{1}{(R+h)}$

$3(R+h) = 4R$

$3R + 3h = 4R$

$3h = R$ or $h = \frac{R}{3}$

37. (d) : Acceleration due to gravity at a height h from the surface of the earth is

$$g_h = \frac{gR^2}{(R+h)^2}$$

where g is the acceleration due to gravity on the surface of the earth and R is the radius of the earth.

$$g_h = g\,\frac{(6400)^2}{(6400+100)^2} = g\left(\frac{6400}{6500}\right)^2 \qquad \text{...(i)}$$

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% change in acceleration due to gravity

$$= \frac{g - g_h}{g} \times 100\% = \left(1 - \frac{g_h}{g}\right) \times 100\%$$

$$= \left(1 - \left(\frac{6400}{6500}\right)^2\right) \times 100\% \quad \text{(Using (i))}$$

$$= 3\%$$

38. (b) : Acceleration due to gravity at a height h above the surface of the earth is

$$g_h = \frac{gR}{(R+h)^2}$$

where R is the radius of the earth

Given : $g_h = 9\ \text{m s}^{-2}$, $h = \frac{R}{20}$

$$\therefore \quad 9 = \frac{gR^2}{\left(R + \frac{R}{20}\right)^2} = g\left(\frac{20}{21}\right)^2 \qquad \ldots\text{(i)}$$

Acceleration due to gravity at depth d below the surface of the earth is

$$g_d = g\left(1 - \frac{d}{R}\right)$$

Here, $d = \frac{R}{20}$

$$\therefore \quad g_d = g\left[1 - \frac{(R/20)}{R}\right]$$

$$g_d = g\left(\frac{19}{20}\right) \qquad \ldots\text{(ii)}$$

Divide (ii) by (i), we get

$$\frac{g_d}{9} = \frac{19}{20} \times \frac{21}{20} \times \frac{21}{20} \quad \text{or} \quad g_d \approx 9.5\ \text{m s}^{-2}$$

39. (b) : Let v be the velocity of projection of body from the surface of the earth.

According to conservation of mechanical energy, we get

$$\frac{1}{2}mv^2 - \frac{GMm}{R} = -\frac{GMm}{R+h}$$

$$v^2 - \frac{2GM}{R} = -\frac{2GM}{R+h}$$

As per question,

$$v = \frac{3}{4}v_e = \frac{3}{4}\sqrt{\frac{2GM}{R}} \qquad \left(\because\ v_e = \sqrt{\frac{2GM}{R}}\right)$$

$$\therefore \quad \left(\frac{3}{4}\sqrt{\frac{2GM}{R}}\right)^2 - \frac{2GM}{R} = -\frac{2GM}{R+h}$$

$$\frac{9}{16}\left(\frac{2GM}{R}\right) - \frac{2GM}{R} = -\frac{2GM}{R+h}$$

$$\frac{18}{16R} - \frac{2}{R} = -\frac{2}{R+h}$$

$$\frac{18-32}{16R} = -\frac{2}{R+h}$$

$$\frac{14}{16R} = \frac{2}{R+h}$$

$$14R + 14h = 32R$$

$$14h = 18R$$

$$h = \frac{18}{14}R = \frac{9}{7}R$$

40. (c) : Kinetic energy of a satellite, $K = \frac{1}{2}mv^2$

or $mv = \sqrt{2Km}$

Angular momentum,

$$L = mvr = (\sqrt{2Km}) \times r = \sqrt{2mKr^2}$$

41. (a) : From conservation of mechanical energy

Decrease in potential energy = Increase in kinetic energy

$$0 - \left(-\frac{Gm_1m_2}{r}\right) = \frac{1}{2}\mu v_r^2$$

Here, $\mu = \left(\frac{m_1m_2}{m_1+m_2}\right)$ = reduced mass

v_r = relative velocity of approach

$$\therefore \quad \frac{Gm_1m_2}{r} = \frac{1}{2}\left(\frac{m_1m_2}{m_1+m_2}\right)v_r^2$$

or $$v_r = \sqrt{\frac{2G(m_1+m_2)}{r}}$$

42. (b) : According to Kepler's second law, equal areas are swept in equal intervals of time.

As area SCD = 2 area SAB, hence $t_1 = 2t_2$

43. (a) : Time period of a revolution of a planet,

$$T = \frac{2\pi r}{v} = \frac{2\pi r}{\sqrt{\frac{GM_S}{r}}} = \frac{2\pi r^{3/2}}{\sqrt{GM_S}}$$

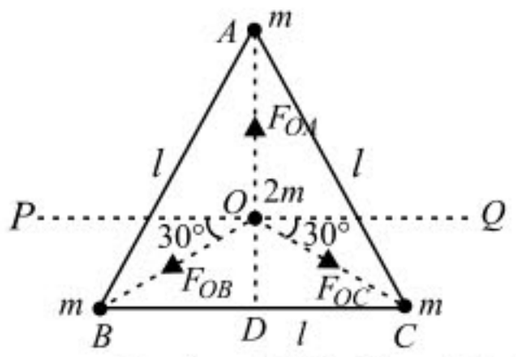
where M_S is the mass of the sun

Squaring both sides, we get

$$T^2 = \frac{4\pi^2 r^3}{GM_S}$$

The graph between T^2 and r^3 is a straight line whose slope is $\frac{4\pi^2}{GM_S}$.

44. (a) :



Draw a perpendicular AD to the side BC.

$$\therefore \quad AD = AB\sin 60^\circ = \frac{\sqrt{3}}{2}l$$

Distance AO of the centroid O from A is $\frac{2}{3}AD$.

$$\therefore \quad AO = \frac{2}{3}\left(\frac{\sqrt{3}}{2}l\right) = \frac{l}{\sqrt{3}}$$

By symmetry, $AO = BO = CO = \frac{l}{\sqrt{3}}$

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Force on mass $2m$ at O due to mass m at A is

$$F_{OA} = \frac{Gm(2m)}{(l/\sqrt{3})^2} = \frac{6Gm^2}{l^2} \text{ along } OA$$

Force on mass $2m$ at O due to mass m at B is

$$F_{OB} = \frac{Gm(2m)}{(l/\sqrt{3})^2} = \frac{6Gm^2}{l^2} \text{ along } OB$$

Force on mass $2m$ at O due to mass m at C is

$$F_{OC} = \frac{Gm(2m)}{(l/\sqrt{3})^2} = \frac{6Gm^2}{l^2} \text{ along } OC$$

Draw a line PQ parallel to BC passing through O. Then

$\angle BOP = 30° = \angle COQ$

Resolving $\vec{F}_{OB}$ and $\vec{F}_{OC}$ into two components.

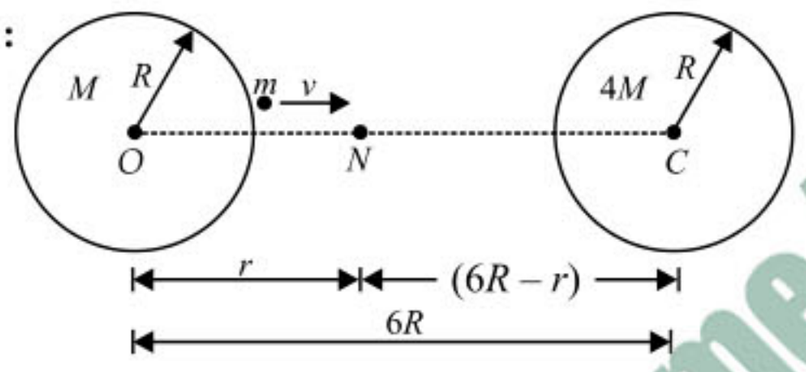
Components acting along OP and OQ are equal in magnitude and opposite in direction. So, they will cancel out while the components acting along OD will add up.

$\therefore$ The resultant force on the mass $2m$ at O is

$$F_R = F_{OA} - (F_{OB}\sin 30° + F_{OC}\sin 30°)$$

$$= \frac{6Gm^2}{l^2} - \left(\frac{6Gm^2}{l^2}\times\frac{1}{2} + \frac{6Gm^2}{l^2}\times\frac{1}{2}\right) = 0$$

45. (c) :



Let the projectile of mass m be fired with minimum velocity, v from the surface of sphere of mass M to reach the surface of sphere of mass $4M$. Let N be neutral point at a distance r from the centre of the sphere of mass M.

At neutral point N,

$$\frac{GMm}{r^2} = \frac{G(4M)m}{(6R-r)^2}$$

$$(6R - r)^2 = 4r^2$$

$$6R - r = \pm 2r \quad \text{or} \quad r = 2R \text{ or } -6R$$

The point $r = -6R$ does not concern us.

Thus, $ON = r = 2R$.

It is sufficient to project the projectile with a speed which would enable it to reach N. Thereafter, the greater gravitational pull of $4M$ would suffice.

The mechanical energy at the surface of M is

$$E_i = \frac{1}{2}mv^2 - \frac{GMm}{R} - \frac{G(4M)m}{5R}$$

At the neutral point N, the speed approaches zero.

$\therefore$ The mechanical energy at N is

$$E_N = -\frac{GMm}{2R} - \frac{G(4M)m}{4R} = -\frac{GMm}{2R} - \frac{GMm}{R}$$

According to law of conservation of mechanical energy,

$$E_i = E_N$$

$$\frac{1}{2}mv^2 - \frac{GMm}{R} - \frac{4GMm}{5R} = -\frac{GMm}{2R} - \frac{GMm}{R}$$

$$v^2 = \frac{2GM}{R}\left[\frac{4}{5} - \frac{1}{2}\right] = \frac{3}{5}\frac{GM}{R}$$

$$\text{or } v = \left(\frac{3}{5}\frac{GM}{R}\right)^{1/2}$$

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Unit Test 1

• Physical World and Measurement
• Motion in a Straight Line • Motion in a Plane
• Laws of Motion • Work, Energy and Power
• System of Particles and Rotational Motion • Gravitation

Unit test is complementary part of the learning process. It gives you a total insight whether the learning outcomes have been achieved or not. After doing daywise preparation, attempt these questions in exam like environment. This will assist you in finding particular area of weakness to work upon. An OMR sheet is given at the end to fill the correct answers.

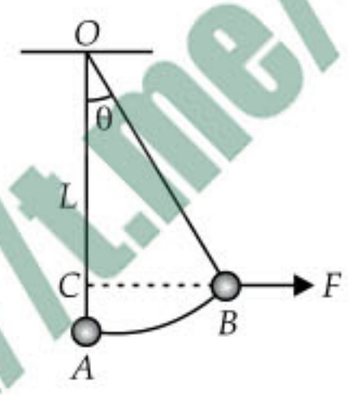
All the Best!

Max. Marks : 180 **Time : 45 min.**

1. Two cars are moving in the same direction with a speed of 30 km h^{-1}. They are separated from each other by 5 km. Third car moving in the opposite direction meets the two cars after an interval of 4 min. What is the speed of the third car?
(a) 30 km h^{-1} (b) 35 km h^{-1}
(c) 40 km h^{-1} (d) 45 km h^{-1}

2. A 24 kg block resting on a floor has a rope tied to its top. The maximum tension, that rope can withstand without breaking is 310 N. The minimum time in which the block can be lifted a vertical distance of 4.6 m by pulling on the rope is
(a) 1.2 s (b) 2.9 s (c) 1.7 s (d) 2.3 s

3. An object of mass m is tied to a string of length L and a variable horizontal force is applied on it which starts at zero and gradually increases until the string makes an angle θ with the vertical. Work done by the force F is



(a) $mgL\,(1 - \sin\theta)$ (b) mgL
(c) $mgL\,(1 - \cos\theta)$ (d) $mgL\,(1 + \cos\theta)$

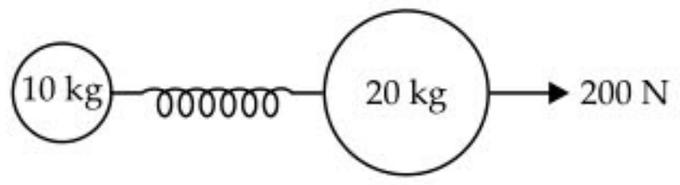
4. A ball falls freely from a height of 45 m. When the ball is at a height of 25 m, it explodes into two equal pieces. One of them moves horizontally with a speed of 10 m s^{-1}. The distance between the two pieces when both strike the ground is
(a) 10 m (b) 20 m (c) 15 m (d) 30 m

5. The ratio of energy required to raise a satellite to a height h above the earth's surface to that required to put it into the orbit is
(a) $h : R$ (b) $h : 2R$ (c) $2h : R$ (d) $R : h$

6. A man of mass m squatting on the ground gets straight up and stands. The force of reaction of ground on the man during the process is
(a) constant and equal to mg in magnitude
(b) constant and greater than mg in magnitude
(c) variable but always greater than mg
(d) at first greater than mg, and later becomes equal to mg.

7. A uniform rod of length l and mass m is swinging freely about a horizontal axis passing through its end. Its maximum angular speed is ω. Its centre of mass rises to a maximum height of
(a) $\frac{1}{3}\frac{l^2\omega^2}{g}$ (b) $\frac{1}{6}\frac{l\omega}{g}$ (c) $\frac{1}{2}\frac{l^2\omega^2}{g}$ (d) $\frac{1}{6}\frac{l^2\omega^2}{g}$

8. Two masses of 10 kg and 20 kg respectively are tied together by a massless spring. A force of 200 N is applied on a 20 kg mass as shown in figure. At the instant shown, the acceleration of 10 kg mass is 12 m s^{-2}, the acceleration of 20 kg mass is



(a) 0 (b) 10 m s^{-2}
(c) 4 m s^{-2} (d) 12 m s^{-2}.

9. The mass of the earth is increasing at the rate of 1 part in 5×10^{19} per day by the attraction of meteors falling normally on the earth's surface. Assuming that the density of earth is uniform, the rate of change of the period of rotation of the earth is
(a) 2.0×10^{-20} (b) 2.66×10^{-19}
(c) 4.33×10^{-18} (d) 5.66×10^{-17}

10. The twisting couple per unit twist for a solid cylinder of radius 3 cm is 0.1 Nm. The twisting couple per unit twist, for a hollow cylinder of same material with outer and inner radius 5 cm and 4 cm respectively will be
(a) 0.1 N m (b) 0.455 N m
(c) 0.91 N m (d) 1.82 N m

11. The Earth is assumed to be a sphere of radius R. A plateform is arranged at a height R from the surface of the Earth. The escape velocity of a body from the plateform is fv, where v is the escape velocity from the surface of the Earth. The value of f is
(a) 1/2 (b) $\sqrt{2}$ (c) $1/\sqrt{2}$ (d) 1/3

12. A stone is lying in a fluid stream. The force acting on it depends on the density of the fluid, the velocity of flow and the maximum area of cross-section perpendicular to the direction of flow. The force F and the velocity v of flow are related as

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(a) $F \propto \frac{1}{v}$ (b) $F \propto v$

(c) $F \propto v^2$ (d) $F \propto \frac{1}{v^2}$

13. A bullet is fired from a gun. The force on the bullet is given by $F = 600 - 2 \times 10^5 t$, where F is in newton and t is in seconds. The force on the bullet becomes zero as soon as it leaves the barrel. What is the average impulse imparted to the bullet?

(a) 9 N s (b) zero (c) 0.9 N s (d) 1.8 N s

14. An object of mass 5 kg falls from rest through a vertical distance of 20 m and acquires a velocity of 10 m s^{-1}. The work done by the push of air on the object is ($g = 10$ m s^{-2})

(a) 250 J (b) – 500 J (c) 750 J (d) – 750 J

15. The escape velocity for a rocket on the Earth is 11.2 km s^{-1}. The escape velocity (in km s^{-1}) from a planet having twice the radius and same mean density is

(a) 11.2 (b) 5.6 (c) 15.2 (d) 22.4

16. A particle is projected vertically upwards with velocity 40 m s^{-1}. What are the displacement and distance travelled by the particle in 6 s?
(Take $g = 10$ m s^{-2}.)

(a) 60 m, 80 m (b) 20 m, 60 m
(c) 60 m, 100 m (d) 100 m, 120 m

17. An 8 kg metal block of dimension 16 cm × 8 cm × 6 cm is lying on a table with its face of largest area touching the table. If $g = 10$ m s^{-2}, the minimum amount of work done in making it stand with its length vertical is

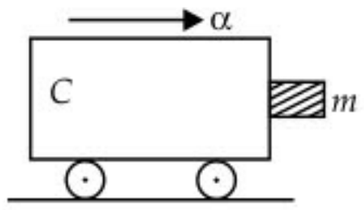
(a) 0.4 J (b) 6.4 J
(c) 4 J (d) 12.8 J

18. Four particles each of mass m are lying symmetrically on the rim of a disc of mass M and radius R. Moment of inertia of this system about an axis passing through one of the particle and perpendicular to plane of disc is

(a) $16mR^2$ (b) $(3M + 16m)\frac{R^2}{2}$

(c) $(3M + 12m)\frac{R^2}{2}$ (d) zero

19. A block of mass m is in contact with the cart C as shown in the figure. The coefficient of static friction between the block and and the cart is μ. The acceleration α of the cart that will prevent the block from falling satisfies



(a) $\alpha > \frac{mg}{\mu}$ (b) $\alpha > \frac{g}{\mu m}$

(c) $\alpha \geq \frac{g}{\mu}$ (d) $\alpha < \frac{g}{\mu}$

20. A spherical planet has a mass M_p and diameter D_p. A particle of mass m falling freely near the surface of this planet will experience an acceleration due to gravity, equal to

(a) $\frac{4GM_p}{D_p^2}$ (b) $\frac{GM_p m}{D_p^2}$

(c) $\frac{GM_p}{D_p^2}$ (d) $\frac{4GM_p m}{D_p^2}$

21. If the change in the value of g at a height h above the surface of the Earth is the same as that at a depth x below it, when both x and h are much smaller than the radius of the Earth, then

(a) $x = h$ (b) $x = 2h$
(c) $x = h/2$ (d) $x = h^2$

22. A particle starts from rest and has an acceleration of 2 m s^{-2} for 10 s. After that, it travels for 30 s with constant speed and then undergoes a retardation of 4 m s^{-2} and comes back to rest. The total distance covered by the particle is

(a) 650 m (b) 750 m
(c) 700 m (d) 800 m

23. A body moves along a circular path of radius 5 m. The coefficient of friction between the surface of the path and the body is 0.5. The angular velocity in rad s^{-1}, with which the body should move so that it does not leave the path is (Take $g = 10$ m s^{-2})

(a) 4 (b) 3
(c) 2 (d) 1

24. The speed of light (c), acceleration due to gravity (g) and pressure (P) are taken as fundamental units, the dimensions of gravitational constant (G) are

(a) $[c^0 g P^{-3}]$ (b) $[c^2 g^3 P^{-2}]$
(c) $[c^0 g^2 P^{-1}]$ (d) $[c^2 g^2 P^{-2}]$

25. At a metro station, a girl walks up a stationary escalator in time t_1. If she remains stationary on the escalator, then the escalator takes her up in time t_2. The time taken by her to walk up on the moving escalator will be

(a) $\frac{(t_1 + t_2)}{2}$ (b) $\frac{t_1 t_2}{(t_2 - t_1)}$

(c) $\frac{t_1 t_2}{(t_2 + t_1)}$ (d) $t_1 - t_2$

26. A body of mass 60 kg is dragged with just enough force to start it moving on a rough surface with coefficients of static and kinetic frictions 0.5 and 0.4 respectively. On applying the same force, the acceleration is

(a) 0.98 m s^{-2} (b) 9.8 m s^{-2}
(c) 0.54 m s^{-2} (d) 5.4 m s^{-2}

27. A block of mass 0.50 kg is moving with a speed of 2.00 m s^{-1} on a smooth surface. It strikes another mass of 1.00 kg at rest and then they move as a single body. The energy loss during the collision is

(a) 0.16 J (b) 1.00 J
(c) 0.67 J (d) 0.34 J

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28. A man stands on a rotating platform with his arms stretched holding a 5 kg weight in each hand. The angular speed of the platform is 1.2 rev s^{-1}. The moment of inertia of the man together with the platform may be taken to be constant and equal to 6 kg m^2. If the man brings his arms close to his chest with the distance of each weight from the axis changing from 100 cm to 20 cm. The new angular speed of the platform is

(a) 2 rev s^{-1} (b) 3 rev s^{-1}
(c) 5 rev s^{-1} (d) 6 rev s^{-1}

29. A projectile has initially the same horizontal velocity as it would acquire if it had moved from rest with uniform acceleration of 3 m s^{-2} for 0.5 minutes. If the maximum height reached by it is 80 m, then the angle of projection is (Take $g = 10$ m s^{-2})

(a) $\tan^{-1}(3)$ (b) $\tan^{-1}\left(\frac{3}{2}\right)$
(c) $\tan^{-1}\left(\frac{4}{9}\right)$ (d) $\sin^{-1}\left(\frac{4}{9}\right)$

30. A horizontal force, just sufficient to move a body of mass 4 kg lying on a rough horizontal surface, is applied on it. The coefficients of static and kinetic friction between the body and the surface are 0.8 and 0.6 respectively. If the force continues to act even after the block has started moving, the acceleration of the block in m s^{-2} is (Take $g = 10$ m s^{-2})

(a) 1/4 (b) 1/2
(c) 2 (d) 4

31. A particle of mass 100 g is thrown vertically upwards with a speed of 5 m s^{-1}. The work done by the force of gravity during the time the particle goes up is

(a) 0.5 J (b) –0.5 J
(c) –1.25 J (d) 1.25 J

32. The moment of inertia of a solid flywheel of radius 0.1 m about its axis is 0.1 kg m^2. A tangential force of 2 kg wt is applied round the circumference of flywheel with the help of string and mass M. The acceleration of the mass is

(a) 18.6 rad s^{-2} (b) 19.6 rad s^{-2}
(c) 14.6 rad s^{-2} (d) 16.7 rad s^{-2}

33. At what distance in metre from the centre of the moon, the intensity of gravitational field will be zero? (Take mass of earth and moon as 5.98×10^{24} kg and 7.35×10^{22} kg respectively and the distance between moon and earth as 3.85×10^8 m.)

(a) zero (b) 3.8×10^7
(c) 8×10^8 (d) 3.7×10^8

34. The dimensional formula for acceleration, velocity and length are $\alpha\beta^{-2}$, $\alpha\beta^{-1}$ and $\alpha\gamma$. What is the dimensional formula for the coefficient of friction?

(a) $\alpha\beta\gamma$ (b) $\alpha^{-1}\beta^0\gamma^0$
(c) $\alpha^0\beta^{-1}\gamma^0$ (d) $\alpha^0\beta^0\gamma^{-1}$

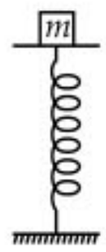
35. A bullet of mass 50 g is fired from a gun of mass 2 kg. If the total kinetic energy produced is 2050 J, the kinetic energy of the bullet and the gun respectively are

(a) 200 J, 5 J (b) 2000 J, 50 J
(c) 5 J, 200 J (d) 50 J, 2000 J

36. Two uniform thin rods each of mass M and length l are placed along X and Y axis with one end of each at the origin. Moment of inertia of the system about Z-axis is

(a) $\frac{3}{2}Ml^2$ (b) $\frac{2}{3}Ml^2$
(c) $2\,Ml^2$ (d) none of these

37. A mass of 2 kg is put on a flat pan attached to a vertical spring fixed on the ground as shown in the figure. The mass of the spring and the pan is negligible. When pressed slightly and released the mass executes a simple harmonic motion. The spring constant is 200 N m^{-1}.



What should be the minimum amplitude of the motion, so that the mass gets detached from the pan? (Take $g = 10$ m s^{-2})

(a) 8 cm
(b) 10 cm
(c) 4 cm
(d) Any value less than 12 cm

38. A ball falls under gravity from a height 10 m with an initial velocity v_0. It hits the ground, loses 50% of its energy in collision and it rises to the same height, what is the value of v_0?

(a) 14 m s^{-1} (b) 7 m s^{-1}
(c) 28 m s^{-1} (d) 9.8 m s^{-1}

39. A bullet of mass 0.01 kg and travelling at a speed of 500 m s^{-1} strikes a block of mass 2 kg, which is is suspended by a string of length 5 m. The centre of gravity of the block is found to rise a vertical distance of 0.1 m. What is the speed of the bullet after it emerges from the block?

(a) 580 m s^{-1} (b) 220 m s^{-1}
(c) 1.4 m s^{-1} (d) 7.8 m s^{-1}

40. A man in a balloon rising vertically with an acceleration of 4.9 m s^{-2} releases a ball 2 s after the balloon is let go from the ground. The greatest height above the ground reached by the ball is (Take $g = 9.8$ m s^{-2})

(a) 14.7 m (b) 19.6 m
(c) 9.8 m (d) 24.5 m

41. A sand bag of mass M is suspended by rope. A bullet of mass m is fired at it with speed v and gets embeded in it. The loss of kinetic energy is

(a) $\frac{Mmv^2}{2(M+m)}$ (b) $\frac{Mv^2}{2(M+m)}$
(c) $\frac{m^2v^2}{2(M+m)}$ (d) $\frac{1}{2}(M+m)v^2$.

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42. A mass of 2.9 kg is suspended from a string of length 50 cm, and is at rest. Another body of mass 100 g, which is moving horizontally with a velocity of 150 m s^{-1} strikes and sticks to it. When the string makes an angle of 60° with the vertical, the tension in the string would be

(a) 270 N (b) 215 N
(c) 135 N (d) 95 N

43. Two blocks of masses 10 kg and 4 kg are connected by a spring of negligible mass and placed on a frictionless horizontal surface. An impulse gives a velocity of 14 m s^{-1} to the heavier block in the direction of the lighter block. The velocity of the centre of mass is

(a) 30 m s^{-1} (b) 20 m s^{-1}
(c) 10 m s^{-1} (d) 5 m s^{-1}

44. Force on a 1 kg mass on earth of radius R is 10 N. Then the force on a satellite revolving around the earth in the mean orbital radius $3R/2$ will be (Take mass of satellite = 100 kg)

(a) 4.44×10^2 N (b) 3.33×10^2 N
(c) 500 N (d) 6.66×10^2 N

45. A particle of mass M is situated at the centre of a spherical shell of same mass and radius a. The gravitational potential at a point situated at distance $a/2$ from the centre, will be

(a) $-\frac{3GM}{a}$ (b) $-\frac{2GM}{a}$
(c) $-\frac{GM}{a}$ (d) $-\frac{4GM}{a}$

UNIT TEST 1 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____

(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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Mechanical Properties of Solids

Elasticity

The property of the body to regain its original configuration (length, volume or shape) when the deforming force is removed, is called elasticity.

Some Terms Related to Elasticity

- **Deforming force:** If a force applied on a body which causes change in the shape or size of the body (either in length, volume or shape) then this force is called deforming force.
- **Perfectly elastic body :** A body which regains its original shape immediately and completely after the removal of deforming force from it, is called a perfectly elastic body. Quartz and phosphor bronze are the examples of nearly perfectly elastic bodies.
- **Perfectly plastic body :** A body which does not regain its original shape or size at all after the removal of the deforming force is called a perfectly plastic body.

Stress

When a deforming force is applied to a body, it changes the shape or size of the body by changing the normal positions of the molecules or atoms of the body. As a result, an internal restoring force comes into play, which tends to bring the body back to its initial shape or size. This internal restoring force acting per unit are is called stress.

$$i.e.,\ \text{Stress} = \frac{\text{restoring force}}{\text{area}}$$

The unit of stress in *SI* system is N m^{-2} or pascal (Pa) and in CGS system is dyne cm^{-2}.

The dimensional formula of stress is same as that of pressure *i.e.* $[ML^{-1}T^{-2}]$.

Type of Stress

Stress are of two types :

- Normal stress
- Tangential or shearing stress

Normal Stress : When a deforming force acts normally over an area of a body, then the internal restoring force set up per unit area of the body is known as normal stress.

Normal stress can be subdivided into following categories :

- **Tensile stress:** If there is an increase in the length or extension of the body in the direction of force applied, the stress set up is known as tensile stress.
- **Compressive stress:** If there is a decrease in length or compression of the body due to force applied, the stress set up is known as compressive stress.
- **Hydraulic stress:** When a solid body undergoes a change in volume without any change in its geometrical shape on applying the force perpendicular to every point on the surface of body, then the restoring force per unit area in the body is known as hydraulic stress. Hydraulic stress is generally possible when a solid spherical body is placed in a fluid under high pressure.

Tensile or compressive stress can also be termed as longitudinal stress.

Tangential or shearing stress: When a deforming force, acting tangentially to the surface of a body produces a change in the shape of the body without any change in volume, then the stress set up in the body is known as tangential stress or shearing stress.

Strain

When a deforming force is applied on a body, there is a change in the shape or size of the body. The body is said to be strained or deformed. The ratio of change in dimension to the original dimension is called strain.

$$i.e.,\ \text{Strain} = \frac{\text{change in dimensions}}{\text{original dimension}}$$

Strain being the ratio of two similar quantities, hence it is a unitless and dimensionless quantity.

Strain are of three types :

- **Longitudinal strain** $= \dfrac{\text{change in length}}{\text{original length}} = \dfrac{\Delta L}{L}$
- **Volumetric strain** $= \dfrac{\text{change in volume}}{\text{original volume}} = \dfrac{\Delta V}{V}$

Shearing strain : When there is change of shape of a body without change its volume, the strain produced is known as shearing strain. If a body is acted upon by an external force tangential to a surface of the body and the opposite surface is being kept fixed, then the angle through which the line perpendicular to the stationary surface is turned is known as angle of a shear ϕ or shearing strain.

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Hooke's law

Hooke's law states that the extension produced in the wire is directly proportional to the load applied within elastic limit. That is within elastic limit, extension ∝ load applied. Later on it was found that this law is applicable to all types of deformations such as compression bending, twisting etc, and thus a modified form of Hooke's law was given as stated below.

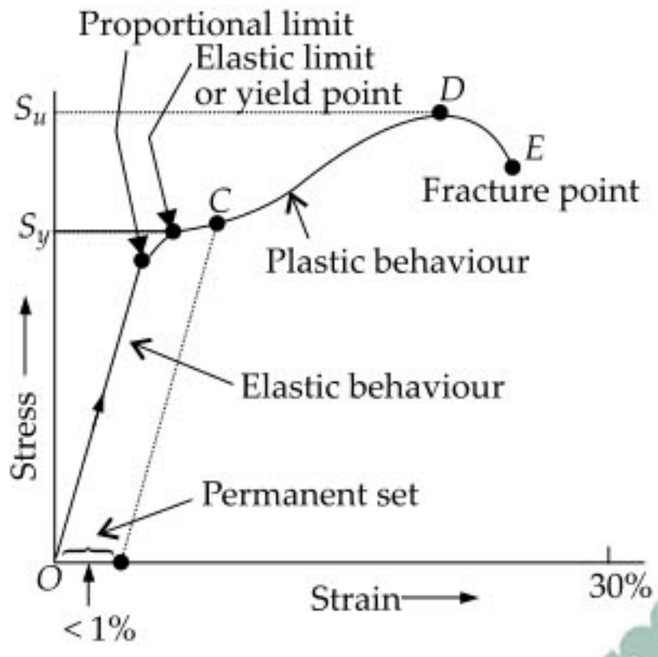
Within elastic limit, the stress developed is directly proportional to the strain produced in a body, that is

Stress ∝ Strain

or Stress = $E \times$ Strain

where E is constant and known as modulus of elasticity

Stress-strain curve: The stress-strain curves vary from material to material. These curves help us to understand how a given material deforms with increasing loads. A typical stress-strain curve for a metal is shown below.



Elastomers: Substances like tissue to aorta, rubber etc. which can be stretched to cause large strains are known as elastromers.

Modulus of Elasticity

According to Hooke's law, within elastic limit,

$$E = \frac{\text{Stress}}{\text{Strain}} = \text{a constant}$$

where E is known as the coefficient of elasticity or, the modulus of elasticity of a body.

It depends upon the nature of material of the body and the manner in which the body is deformed.

Types of modulus of elasticity

Corresponding to the three types of strain, there are three types of modulus of elasticity as described below.

- **Young's modulus of elasticity :** It is defined as the ratio of normal stress to the longitudinal. Strain within the elastic limit.

$$\text{Thus, } Y = \frac{\text{normal stress}}{\text{longitudinal strain}} = \frac{F/\pi r^2}{l/L} = \frac{mgL}{\pi r^2 l}$$

Normal stress is constant for any area of cross-section.

- **Bulk modulus of elasticity :** It is defined as the ratio of normal stress to the volumetric strain, within the elastic limit.

$$\text{Thus, } K = \frac{\text{normal stress}}{\text{volumetric strain}}$$

$$\therefore \quad K = -\frac{P}{\Delta V / V} = -\frac{PV}{\Delta V}$$

- **Modulus of rigidity :** It is defined as, the ratio of tangential stress to the shearing strain, within the elastic limit. It is also called shear modulus of rigidity.

$$\text{Thus, } \eta = \frac{\text{tangential stress}}{\text{shearing strain}}$$

$$\eta = \frac{F/A}{\theta} = \frac{F}{A\theta}$$

The values of moduli of elasticity are independent of the magnitude of the stress and strain. They depend only on the nature of the material of the body.

For a given material there can be different moduli of elasticity depending on the type of stress applied and the strain resulting.

The moduli of elasticity have same dimensional formula and units as that of stress since strain is dimensionless, *i.e.*, the dimensional formula for Y, B and η is $[ML^{-1}T^{-2}]$ while the SI unit of Y, B and η is N m^{-2} or Pa and the CGS unit of Y, B and η is dyne cm^{-2}.

Young's modulus is defined only for solids, but not for liquids and gases.

Young's modulus of a rigid body is infinity.

Greater the value of Young's modulus of a material, larger is its elasticity. Therefore steel is more elastic than rubber.

The reciprocal of bulk modulus is known as compressibility.

$$\text{Compressibility} = \frac{1}{B}$$

The SI unit of compressibility is N^{-1} m^2 and CGS unit is dyne^{-1} cm^2.

Bulk modulus is relevant for solids, liquids and gases.

Bulk modulus of gases is very low while that for liquids and solids is very high.

i.e. $\quad B_{\text{solid}} > B_{\text{liquid}} > B_{\text{gas}}$

For gases, bulk modulus are of two types:

- Isothermal bulk modulus $B_{\text{iso}} = P$ (pressure exerted by the gas)
- Adiabatic bulk modulus $B_{\text{ad}} = \gamma P$

  where $\gamma = C_P/C_V$.

  $\therefore \quad \frac{B_{\text{ad}}}{B_{\text{iso}}} = \gamma > 1; \quad B_{\text{ad}} > B_{\text{iso}}$

  Therefore adiabatic bulk modulus is greater than isothermal bulk modulus.

η is the characteristic of solid material only as the liquids and gases do not have fixed shape. η for liquid is zero.

Poisson's ratio (σ) : $\frac{\text{lateral strain}}{\text{longitudinal strain}} = \frac{-\Delta r/r}{\Delta L/L}$

where L is the original length of the wire, ΔL the increase in length, r is the original radius and Δr is the change in radius.

- σ has no units and dimensions.
- Theoretically, σ lies between –1 and $+\frac{1}{2}$.
- Practically σ lies between zero and $+\frac{1}{2}$.

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Relations among elastic constants (Y, B, η and σ)

- $Y = 3B(1 - 2\sigma)$
- $Y = 2\eta(1 + \sigma)$
- $\sigma = \dfrac{3B - 2\eta}{2\eta + 6B}$
- $\dfrac{9}{Y} = \dfrac{1}{B} + \dfrac{3}{\eta}$

Breaking force = Breaking stress × Area of cross section of the wire.

Work done in a stretched wire,

$$W = \frac{1}{2} \times \text{stress} \times \text{strain} \times \text{volume}$$

$$= \frac{1}{2}\frac{F}{A} \times \frac{\Delta L}{L} \times AL = \frac{1}{2}F \times \Delta L$$

$$= \frac{1}{2} \times \text{load} \times \text{elongation}$$

This work done is stored in the wire as its elastic potential energy or strain energy.

Elastic potential energy stored per unit volume of a stretched wire,

$$u = \frac{1}{2} \times \text{stress} \times \text{strain} = \frac{1}{2} \times Y \times (\text{strain})^2$$

Young's modulus is numerically equal to the stress which will double the length of a wire.

Applications of Elastic Behaviour of Materials

- Beam : A rod or a bar of circular or rectangular cross section with its length very much greater than its thickness is known as beam.
- Cantilever: A beam fixed at one end and loaded at the other is known as cantilever.
- Depression of a beam loaded at the middle by a load W and supported at the ends

$$\delta = \frac{WL^3}{48YI_g}$$

where L is the length of a beam, Y is the Young's modulus for the material of the beam, and I_g is the geometrical moment of inertia.

- Depression of a cantilever at a free end

$$\delta = \frac{WL^3}{3YI_g}$$

- For a beam of circular cross-section of radius r,

$$I_g \frac{\pi r^2}{4}$$

For a beam of rectangular cross-section of breadth b and thikckness d, $I_g = \dfrac{bd^3}{12}$

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EXAM DRILL

1. Force constant of a spring (k) is analogous to

(a) $\frac{YA}{L}$ (b) $\frac{YL}{A}$

(c) $\frac{AL}{Y}$ (d) ALY

2. The Young's modulus of brass and steel are respectively 1.0×10^{11} N m^{-2} and 2.0×10^{11} N m^{-2}. A brass wire and a steel wire of the same length are extended by 1 mm each under the same force. If radii of brass and steel wires are R_B and R_S respectively, then

(a) $R_S = \sqrt{2}\, R_B$ (b) $R_S = \frac{R_B}{\sqrt{2}}$

(c) $R_S = 4R_B$ (d) $R_S = \frac{R_B}{2}$

3. Modulus of rigidity of ideal liquids is

(a) infinity
(b) zero
(c) unity
(d) some finite small non-zero constant value

4. Which of the statements is incorrect ?

(a) Steel is more elastic than rubber.
(b) The stretching of a coil is determined by its shear modulus.
(c) Stress is a vector quantity.
(d) Metals have larger values of Young's modulus than alloys and elastomers.

5. The ratio of tensile stress to the longitudinal strain is defined as

(a) bulk modulus (b) Young's modulus
(c) shear modulus (d) compressibility

6. The average depth of Indian ocean is about 3000 m. The fractional compression, $\frac{\Delta V}{V}$ of water at the bottom of the ocean is
(Given : Bulk modulus of the water = 2.2×10^9 N m^{-2} and $g = 10$ m s^{-2})

(a) 0.82% (b) 0.91%
(c) 1.36% (d) 1.24%

7. A structural steel rod has a radius of 10 mm and a length of 1 m. A 100 kN force stretches it along its length. The strain on the rod is
($Y_{steel} = 200 \times 10^9$ N m^{-2})

(a) 1.6 mm (b) 2.6 mm
(c) 3.6 mm (d) 4.6 mm

8. A wire of length L and radius r is clamped at one end. On stretching the other end of the wire with a force F, the increase in its length is l. If another wire of same material but of length $2L$ and radius $2r$ is stretched with a force $2F$, the increase in its length will be

(a) $\frac{l}{4}$ (b) $\frac{l}{2}$

(c) l (d) $2l$

9. Which of the following substances has highest value of Young's modulus?

(a) Aluminium (b) Iron
(c) Copper (d) Steel

10. Two wires of equal length and cross-section are suspended as shown. Their Young's modulii are Y_1 and Y_2 respectively. The equivalent Young's modulus will be

(a) $Y_1 + Y_2$ (b) $\frac{Y_1 + Y_2}{2}$

(c) $\frac{Y_1 Y_2}{Y_1 + Y_2}$ (d) $\sqrt{Y_1 Y_2}$

11. The radii and Young's moduli of two uniform wires A and B are in the ratio 2 : 1 and 1 : 2 respectively. Both wires are subjected to the same longitudinal force. If the increase in length of the wire A is one percent, the percentage increase in length of the wire B is

(a) 1.0 (b) 1.5
(c) 2.0 (d) 3.0

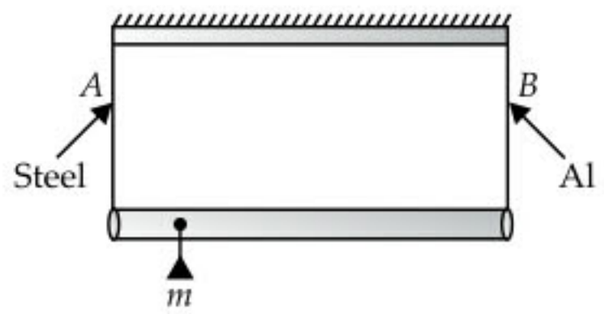
12. Which one of the following statements are wrong?

(a) Young's modulus for a perfectly rigid body is zero.
(b) Bulk modulus is relevant for solids, liquids and gases.
(c) The Young's modulus and shear modulus are relevant for solids.
(d) The stretching of a coil spring is determined by its shear modulus.

13. Young's modulus of the wire depends on

(a) length of the wire
(b) diameter of the wire
(c) material of the wire
(d) mass hanging from the wire

14. A rod of length L and negligible mass is suspended at its two ends by two wires of steel (wire A) and aluminium (wire B) of equal lengths as shown in the figure. The cross-sectional areas of wires A and B are 1 mm^2 and 2 mm^2 respectively.
($Y_{Al} = 70 \times 10^9$ N m^{-2} and $Y_{steel} = 200 \times 10^9$ N m^{-2})



To have equal stress in both the wires, mass m should be suspended at a distance of

(a) $\frac{1}{3}L$ from the wire A (b) $\frac{1}{2}L$ from the wire B

(c) $\frac{2}{3}L$ from the wire B (d) $\frac{2}{3}L$ from the wire A

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15. In the question number 14, to have equal strain in both the wires, mass m should be suspended at a distance of

(a) $\frac{10}{17}L$ from the wire A

(b) $\frac{10}{17}L$ from the wire B

(c) $\frac{7}{17}L$ from the wire B

(d) $\frac{1}{2}L$ from the wire A

16. A wire is suspended from the ceiling and stretched under the action of a weight F suspended from its other end. The force exerted by the ceiling on it is equal and opposite to the weight.

(a) Tensile stress at any cross section A of the wire is F/A.

(b) Tensile stress at any cross section is zero.

(c) Tensile stress at any cross section A of the wire is $2F/A$.

(d) Tension at any cross section A of the wire is $2F$.

17. The maximum load a wire can withstand without breaking, when its length is reduced to half of its original length, will

(a) be doubled (b) be half

(c) be four times (d) remain same

18. A steel rod of length 1 m and area of cross-section 1 cm^2 is heated from 0°C to 200°C, without being allowed to extend or bend. The tension produced in the rod is (Given : Young's modulus of steel = 2×10^{11} N m^{-2} and coefficient of linear expansion of steel = 10^{-5} $°C^{-1}$)

(a) 4×10^3 N (b) 4×10^4 N

(c) 4×10^5 N (d) 4×10^6 N

19. A copper wire of length 2.4 m and a steel wire of length 1.6 m, both of diameter 3 mm, are connected end to end. When stretched by a load, the net elongation is found to be 0.7 mm. The load applied is

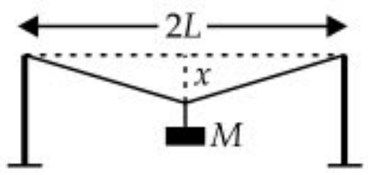
$Y_{copper} = 1.2 \times 10^{11}$ N m^{-2}

$Y_{steel} = 2 \times 10^{11}$ N m^{-2}

(a) 1.2×10^2 N (b) 1.8×10^2 N

(c) 2.4×10^2 N (d) 3.2×10^2 N

20. A mild steel wire of length $2L$ and cross-sectional area A is stretched, well within elastic limit, horizontally between two pillars as shown in the figure. A mass M is suspended from the mid-point of the wire. Strain in the wire is



(a) $\frac{x^2}{2L^2}$

(b) $\frac{x}{L}$

(c) $\frac{x}{L^2}$ (d) $\frac{x}{2L}$

21. In the question number 20, stress in the wire is

(a) $\frac{4xMg}{LA}$ (b) $\frac{2xMg}{lA}$

(c) $\frac{MgL}{4xA}$ (d) $\frac{MgL}{2xA}$

22. A rigid bar of mass M is supported symmetrically by three wires each of length L. Those at each end are of copper and the middle one is of iron. The ratio of their diameters, if each is to have the same tension, is equal to

(a) $\frac{Y_{copper}}{Y_{iron}}$ (b) $\sqrt{\frac{Y_{iron}}{Y_{copper}}}$

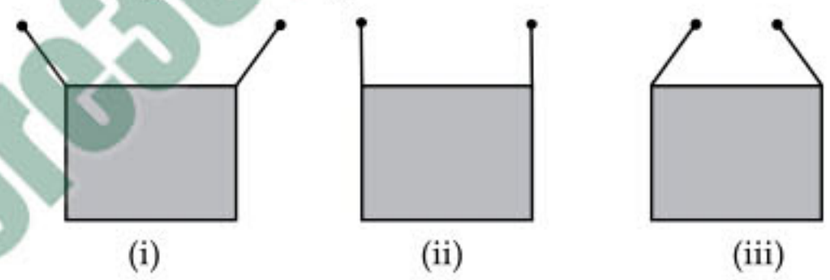
(c) $\frac{Y_{iron}^2}{Y_{copper}^2}$ (d) $\frac{Y_{iron}}{Y_{copper}}$

23. A square lead slab of side 50 cm and thickness 10 cm is subjected to a shearing force (on its narrow face) of 9×10^4 N. The lower edge is riveted to the floor. How much will the upper edge be displaced? Shear modulus of lead = 5.6×10^9 N m^{-2}

(a) 0.16 mm (b) 1.6 mm

(c) 0.16 cm (d) 1.6 cm

24. A rectangular frame is to be suspended symmetrically by two strings of equal length on two supports as shown in the figure. It can be done in one of the following three ways



The tension in the strings will be

(a) the same in all cases

(b) least in (i)

(c) least in (ii)

(d) least in (iii)

25. Two wires of same material and length but diameter in the ratio 1 : 2 are stretched by the same force. The potential energy per unit volume for the two wires when stretched will be in the ratio

(a) 16 : 1 (b) 4 : 1

(c) 2 : 1 (d) 1 : 1

26. For most materials the Young's modulus is n times the modulus of rigidity, where n is

(a) 2 (b) 3

(c) 4 (d) 5

27. A steel wire of length 4.5 m and cross-sectional area 3×10^{-5} m^2 stretches by the same amount as a copper wire of length 3.5 m and cross-sectional area of 4×10^{-5} m^2 under a given load. The ratio of the Young's modulus of steel to that of copper is

(a) 1.3 (b) 1.5

(c) 1.7 (d) 1.9

28. A spring is stretched by applying a load to its free end. The strain produced in the spring is

(a) volumetric (b) shear

(c) longitudinal and shear (d) longitudinal

29. The temperature of a wire is doubled. The Young's modulus of elasticity

(a) will also double

(b) will become four times

(c) will remain same

(d) will decrease

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30. To what depth must a rubber ball be taken in deep sea so that its volume is decreased by 0.1%.
(Take, density of sea water = 10^3 kg m^{-3}, bulk modulus of rubber = 9×10^8 N m^{-2}, $g = 10$ m s^{-2})
(a) 9 m (b) 18 m
(c) 90 m (d) 180 m

31. Choose the wrong statement.
(a) The bulk modulus for solids is much larger than for liquids.
(b) Gases are least compressible.
(c) The reciprocal of the bulk modulus is called compressibility.
(d) For a system in equilibrium, the value of bulk modulus is always positive.

32. Substances like tissue of aorta, rubber etc. which can be stretched to cause large strains are called
(a) polymers (b) plastomers
(c) fibres (d) elastomers

33. A bar of length l, breadth b and depth d is supported at its ends and is loaded at the centre by a load W. If Y is the Young's modulus of the material of the bar, then the depression δ at the centre is
(a) $\frac{Wl^3}{4bd^3Y}$ (b) $\frac{Wb^3}{4dl^3Y}$
(c) $\frac{Wd^3}{4lb^3Y}$ (d) $\frac{Wl^3}{bd^3Y}$

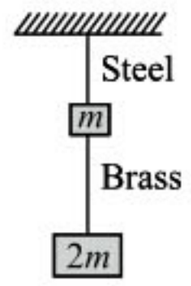
34. The shear modulus is also known as
(a) bulk modulus
(b) Young's modulus
(c) modulus of rigidity
(d) Possion's ratio

35. Which one of the following statements is correct? In the case of
(a) shearing stress there is change in volume.
(b) hydraulic stress there is no change in shape.
(c) shearing stress there is no change in shape.
(d) hydraulic stress there is no change in volume.

36. A thick rope of rubber of density 1.5×10^3 kg m^{-3} and Young's modulus 5×10^6 N m^{-2}, 8 m in length is hung from the ceiling of a room. The increase in its length due to its own weight is (Take $g = 10$ m s^{-2})
(a) 9.6×10^{-2} m (b) 9.6×10^{-5} m
(c) 9.6×10^{-7} m (d) 9.6 m

37. A uniform plank of Young's modulus Y is moved over a smooth horizontal surface by a constant horizontal force F_0. The area of cross-section of the plank is A. The compressive strain on the plank in the direction of the force is
(a) $\frac{F_0}{AY}$ (b) $\frac{2F_0}{AY}$
(c) $\frac{F_0}{2AY}$ (d) $\frac{3F_0}{2AY}$

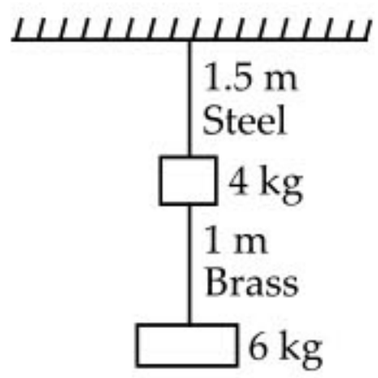
38. If the ratio of lengths, radii and Young's modulii of steel and brass wires in the figure are a, b, c respectively. Then the corresponding ratio of increase in their lengths would be
(a) $\frac{2ac}{b^2}$ (b) $\frac{3a}{2b^2c}$
(c) $\frac{3c}{2ab^2}$ (d) $\frac{2a^2c}{b}$



39. The Poisson's ratio of the material is 0.5. If a force is applied to a wire of this material, there is a decrease in the cross-sectional area by 4%. The percentage increase in its length is
(a) 1% (b) 2%
(b) 2.5% (d) 4%

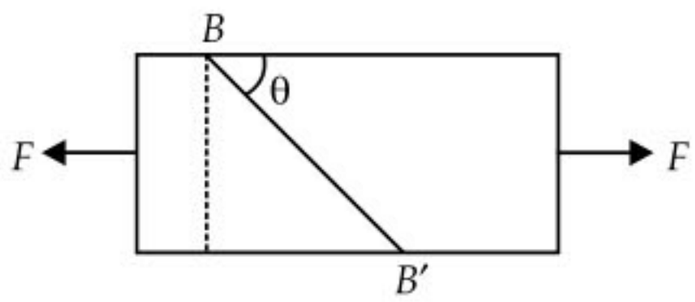
40. An iron bar of length l and having a cross-section A is heated from 0° to 100° C. If this bar is so hold that it is not permitted to expand or bend, the force that is developed is
(a) inversely proportional to the cross-sectional area of the bar
(b) independent of the length of the bar
(c) inversely proportional to the length of the bar
(d) directly proportional to the length of the bar

41. Two wires of diameter 0.25 cm, one made of steel and the other made of brass are loaded as shown in figure. The unloaded length of steel wire is 1.5 m and that of brass wire is 1 m.
($Y_{Steel} = 2 \times 10^{11}$ N m^{-2}, $Y_{Brass} = 1 \times 10^{11}$ N m^{-2})



The ratio of elongations of the steel wire to that of brass wire is
(a) $\frac{4}{5}$ (b) $\frac{5}{4}$ (c) $\frac{3}{5}$ (d) $\frac{5}{3}$

42. A bar of cross-section area A is subjected two equal and opposite tensile forces at its ends as shown in figure. Consider a plane BB' making an angle θ with the length.



The ratio of tensile stress to the shearing stress on the plane BB' is

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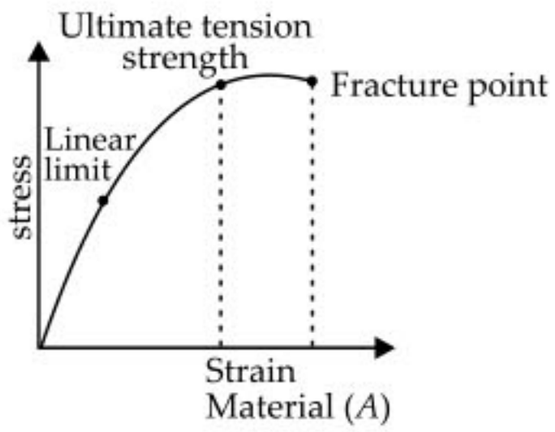
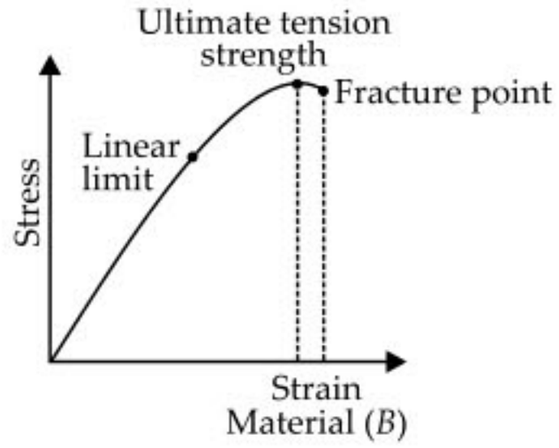
(a) $\tan\theta$ (b) $\sec\theta$
(c) $\cot\theta$ (d) $\cos\theta$

43. In the question number 42, for what value of θ, shearing stress is maximum?
(a) 0°
(b) 30°
(c) 45°
(d) 90°

44. The stress-strain graphs for two materials A and B are shown in figure.

(Assume same scale)





(a) Material A is more brittle than material B.
(b) Material B is more brittle than material A.
(c) Materials A and B have the same brittleness.
(d) Information is insufficient.

45. Two strips of metal are riveted together at their ends by four rivets, each of diameter 6 mm. Assume that each rivet is to carry one quarter of the load. If the shearing stress on the rivet is not to exceed 6.9×10^7 Pa, the maximum tension that can be exerted by the riveted strip is
(a) 2×10^3 N (b) 3.9×10^3 N
(c) 7.8×10^3 N (d) 15.6×10^3 N

DAY 08 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____
(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (a) : $Y = \dfrac{FL}{A\Delta L}$ or $F = \left(\dfrac{YA}{L}\right)\Delta L$

Comparing this with $F = k\Delta x$, we get $k = \dfrac{YA}{L}$

2. (b) : Increase in length

$$\Delta L = \frac{FL}{YA} = \frac{FL}{Y\pi R^2}$$

As F, L and ΔL are same hence,

YR^2 = a constant

$$\therefore \quad 2.0\times10^{11}R_S^2 = 1.0\times10^{11}R_B^2 \Rightarrow \quad R_S = \frac{R_B}{\sqrt{2}}$$

3. (b) : Modulus of rigidity of ideal liquids is zero.

4. (c) : Stress is not a vector quantity as it cannot be assigned a specific direction. It is a tensor quantity.

5. (b) : Young's modulus is defined as the ratio of tensile (or compressive) stress to the longitudinal strain.

6. (c) : The pressure exerted by a 3000 m column of water on the bottom layer is

$$P = h\rho g$$
$$= 3000\ \text{m} \times 1000\ \text{kg m}^{-3} \times 10\ \text{m s}^{-2}$$
$$= 3 \times 10^7\ \text{N m}^{-2}$$

Fractional compression $\dfrac{\Delta V}{V}$ is

$$\frac{\Delta V}{V} = \frac{P}{B} = \frac{3\times10^7\ \text{N m}^{-2}}{2.2\times10^9\ \text{N m}^{-2}} = 1.36\times10^{-2} = 1.36\%.$$

7. (a) : Here, $r = 10\ \text{mm} = 10\times10^{-3}\ \text{m}$

$L = 1\ \text{m}$

$F = 100\ \text{kN} = 100\times10^3\ \text{N} = 10^5\ \text{N}$

Stress on the rod is given by

$$\text{Stress} = \frac{F}{A} = \frac{F}{\pi r^2}$$
$$= \frac{100\times10^3\ \text{N}}{3.14\times(10^{-2}\ \text{m})^2} = 3.18\times10^8\ \text{N m}^{-2}$$

Elongation,

$$\Delta L = \frac{(F/A)L}{Y} = \frac{(3.18\times10^8\ \text{N m}^{-2})(1\ \text{m})}{2\times10^{11}\ \text{N m}^{-2}}$$
$$= 1.59\times10^{-3}\ \text{m} = 1.59\ \text{mm}$$

The strain on the rod is given by

$$\text{Strain} = \frac{\Delta L}{L}$$
$$= \frac{1.59\times10^{-3}\,\text{m}}{1\ \text{m}} = 1.59\times10^{-3}\ \text{m} = 1.59\ \text{mm}$$
$$= 1.6\ \text{mm}$$

8. (c) : Let Y be the Young's modulus of the material of the wire. Then

For the first wire

$$Y = \frac{F/\pi r^2}{l/L} = \frac{FL}{\pi r^2 l} \qquad ...(i)$$

As both the wires are made of the same material, so their Young modulus is same.

Let the extension produced in second wire be l'. Then

$$Y = \frac{2F/\pi(2r)^2}{l'/2L} = \frac{FL}{\pi r^2 l'} \qquad ...(ii)$$

Equating (i) and (ii), we get

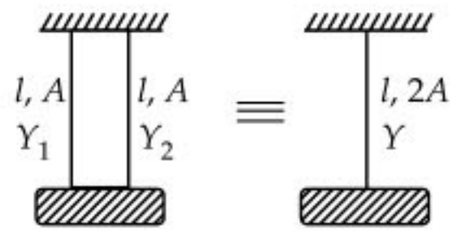
$$\frac{FL}{\pi r^2 l} = \frac{FL}{\pi r^2 l'} \quad \text{or} \quad l' = l$$

9. (d) :

Substance	Young's modulus $10^9\ \text{N m}^{-2}$
Aluminium	70
Copper	120
Iron	190
Steel	200

From the table, it is clear that among the given substances steel has the highest value of Young's modulus.

10. (b) :



Spring constant of a wire is given by

$$k = \frac{YA}{l}$$

Refer figure. The equivalent spring constant of wire is

$$k_{eq} = k_1 + k_2$$

or $\dfrac{Y(2A)}{l} = \dfrac{Y_1A}{l} + \dfrac{Y_2A}{l}$ or $Y = \dfrac{Y_1 + Y_2}{2}$

11. (c) : Young's modulus, $Y = \dfrac{FL}{\pi r^2 \Delta L}$

or $\dfrac{\Delta L}{L} = \dfrac{F}{\pi r^2 Y}$

For the same force,

$$\frac{\Delta L}{L} \propto \frac{1}{r^2 Y}$$

$$\therefore \quad \frac{\Delta L_B}{L_B}\Big/\frac{\Delta L_A}{L_A} = \left(\frac{r_A}{r_B}\right)^2\left(\frac{Y_A}{Y_B}\right) = \left(\frac{2}{1}\right)^2\left(\frac{1}{2}\right) = 2$$

$$\frac{\Delta L_B}{L_B} = 2\left(\frac{\Delta L_A}{L_A}\right)$$

$$\frac{\Delta L_B}{L_B}\times100 = 2\left(\frac{\Delta L_A}{L_A}\times100\right) = 2\%$$

12. (a) : Young's modulus for a perfectly rigid body is not zero but infinity.

13. (c) : Young's modulus of wire depends only on the nature of the material of the wire.

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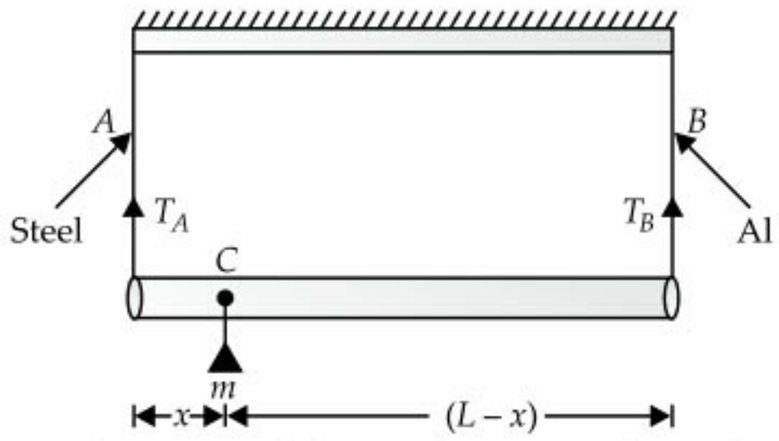
14. (d) : All other statements are correct.



Let mass m be suspended at a distance x from the wire A. Let T_A and T_B be tensions in the wire A (steel) and wire B (aluminium) respectively.

$\therefore$ Stress in wire $A = \dfrac{T_A}{A_A}$

Stress in wire $B = \dfrac{T_B}{A_B}$

For equal stress in both the wires,

$$\frac{T_A}{A_A} = \frac{T_B}{A_B}$$

$$\frac{T_A}{T_B} = \frac{A_A}{A_B} = \frac{1\text{ mm}^2}{2\text{ mm}^2} = \frac{1}{2} \qquad \text{...(i)}$$

As the system is in equilibrium, taking moments about C, we get

$$T_A x = T_B(L - x)$$

$$\frac{L-x}{x} = \frac{T_A}{T_B}$$

$$\frac{L-x}{x} = \frac{1}{2} \qquad \text{(Using (i))}$$

$$2L - 2x = x \quad \text{or} \quad x = \frac{2}{3}L$$

15. (b) : As, $\text{Strain} = \dfrac{\text{Stress}}{\text{Young's modulus}}$

$\therefore$ Strain in wire $A = \dfrac{T_A}{A_A Y_A}$

Strain in wire $B = \dfrac{T_B}{A_B Y_B}$

For equal strain in both the wires,

$$\frac{T_A}{A_A Y_A} = \frac{T_B}{A_B Y_B}$$

$$\therefore \quad \frac{T_A}{T_B} = \frac{A_A}{A_B}\frac{Y_A}{Y_B}$$

$$= \frac{1\text{mm}^2}{2\text{mm}^2} \times \frac{200 \times 10^9\ \text{N m}^{-2}}{70 \times 10^9\ \text{N m}^{-2}} = \frac{10}{7} \qquad \text{... (ii)}$$

As the system is in equilibrium, taking moments about C, we get

$$T_A x = T_B(L - x)$$

$$\frac{L-x}{x} = \frac{T_A}{T_B}$$

$$\frac{L-x}{x} = \frac{10}{7} \quad \text{(Using (ii))}$$

$$7L - 7x = 10x \quad \text{or} \quad 17x = 7L \text{ or } x = \frac{7}{17}L$$

$$\therefore \quad L - x = \frac{10}{17}L$$

16. (a) : When a wire is suspended from the ceiling and stretched under the action of a weight (F) suspended from its other end, the force exerted by the ceiling on it is equal and opposite to the weight. However, the tension at any cross-section A of the wire is just F and not $2F$. Hence, tensile stress which is equal to the tension per unit area is equal to F/A.

17. (d) : Breaking force = Breaking stress × Area of cross-section. When the wire is cut to half, there is no change in the area of cross-section of the wire. Therefore, there is no change in the maximum load (*i.e.*, breaking force) the wire can support.

18. (b) : Let ΔL be increase in the length of the rod due to increase in temperature of the rod. Then

$$\Delta L = L\alpha\Delta T$$

where, α is the coefficient of the linear expansion, ΔT is the rise in temperature and L is the length of the rod.

$$\therefore \quad \frac{\Delta L}{L} = \alpha\Delta T \qquad \text{...(i)}$$

Let the compressive tension of the rod be T and A be cross-section area. Then

$$Y = \frac{T/A}{\Delta L/L}$$

$$\therefore \quad T = Y\frac{\Delta L}{L}A = Y \times \alpha\Delta T \times A \qquad \text{(Using (i))}$$

Here, $Y = 2 \times 10^{11}\ \text{N m}^{-2}$

$\alpha = 10^{-5}°\text{C}^{-1}$

$\Delta T = 200°\text{C} - 0°\text{C} = 200°\text{C}$

$L = 1\text{ m}$, $A = 1\text{ cm}^2 = 1 \times 10^{-4}\text{ m}^2$

$\therefore \quad T = 2 \times 10^{11}\ \text{N m}^{-2} \times 10^{-5}°\text{C}^{-1} \times 200°\text{C} \times 1 \times 10^{-4}\text{ m}^2$

$= 4 \times 10^4\text{ N}$

19. (b) : Let the load applied be W.

Since both the wires have the same tension (equal to the load W) and same area of cross-section A, hence both wires have the same tensile stress.

As Stress = Strain × Young's modulus

$$\therefore \quad \frac{W}{A} = Y_C \times \frac{\Delta L_C}{L_C} = Y_S \times \frac{\Delta L_S}{L_S} \qquad \text{... (i)}$$

where the subscripts C and S refer to copper and steel respectively

$$\therefore \quad \frac{\Delta L_C}{\Delta L_S} = \frac{L_C}{L_S} \times \frac{Y_S}{Y_C}$$

Here,

For copper wire, $L_C = 2.4\text{ m}$,

$Y_C = 1.2 \times 10^{11}\ \text{N m}^{-2}$

For steel wire, $L_S = 1.6\text{ m}$

$Y_S = 2 \times 10^{11}\ \text{N m}^{-2}$

$$\therefore \quad \frac{\Delta L_C}{\Delta L_S} = \left(\frac{2.4\text{ m}}{1.6\text{ m}}\right) \times \frac{(2 \times 10^{11}\ \text{N m}^{-2})}{(1.2 \times 10^{11}\ \text{N m}^{-2})} = \frac{5}{2} \qquad \text{...(ii)}$$

The total elongation is

$$\Delta L_C + \Delta L_S = 0.7\text{ mm} = 7 \times 10^{-4}\text{ m} \qquad \text{...(ii)}$$

Solving rq. (i) and (ii), we get

$\Delta L_C = 5 \times 10^{-4}\text{ m}$ and $\Delta L_S = 2 \times 10^{-4}\text{ m}$

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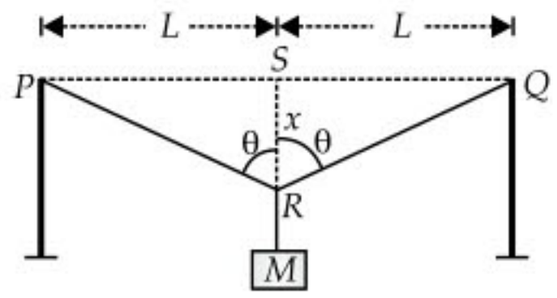
From Eq. (i)

$$W = A \times Y_C \times \frac{\Delta L_C}{L_C}$$

$$= \pi \times (1.5 \times 10^{-3}\,\text{m})^2 \times 1.2 \times 10^{11}\,\text{N m}^{-2} \times \frac{5 \times 10^{-4}\,\text{m}}{2.4\,\text{m}}$$

$$= 1.8 \times 10^2\,\text{N}$$

20. (a) :



Refer figure,

Increase in length $\Delta L = (PR + RQ) - PQ = 2PR - PQ$

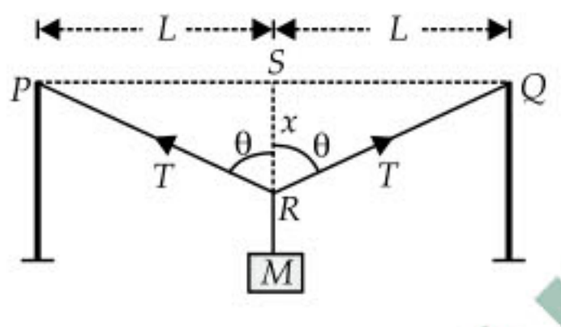
$$\Delta L = 2(L^2 + x^2)^{1/2} - 2L = 2L\left(1 + \frac{x^2}{L^2}\right)^{1/2} - 2L$$

$$= 2L\left[1 + \frac{1}{2}\frac{x^2}{L^2}\right] - 2L \quad \text{(By binomial theorem)}$$

$$= \frac{x^2}{L}$$

$$\therefore \text{ Strain} = \frac{\Delta L}{2L} = \frac{x^2}{2L^2}$$

21. (d) : Let T be the tension in the wire.



Refer figure,

In equilibrium, $2T\cos\theta = Mg$ or $T = \frac{Mg}{2\cos\theta}$

But $\cos\theta = \frac{x}{\sqrt{L^2 + x^2}}$

$$= \frac{x}{L\left(1 + \frac{x^2}{L^2}\right)^{1/2}} = \frac{x}{L\left(1 + \frac{1}{2}\frac{x^2}{L^2}\right)}$$

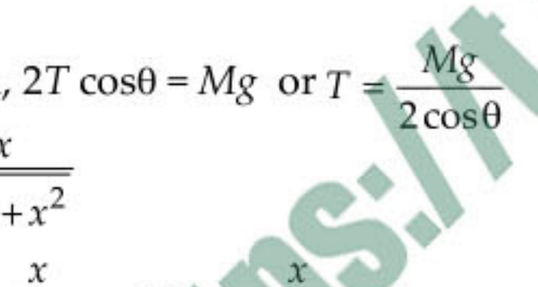
As $\frac{x}{L}$ is a small quantity so $\frac{x^2}{2L^2} << 1$,

so $\frac{x^2}{2L^2}$ can be neglected.

$$\therefore \quad \cos\theta = \frac{x}{L} \text{ and } T = \frac{Mg}{2(x/L)} = \frac{MgL}{2x}$$

$$\therefore \text{ Stress} = \frac{T}{A} = \frac{MgL}{2Ax}$$

22. (b) : The situation is as shown in the figure.



Let T be tension in each wire.

As the bar is supported symmetrically by the three wires, therefore extension in each wire is same.

As $Y = \frac{F/A}{\Delta L/L}$

If D is the diameter of the wire, then

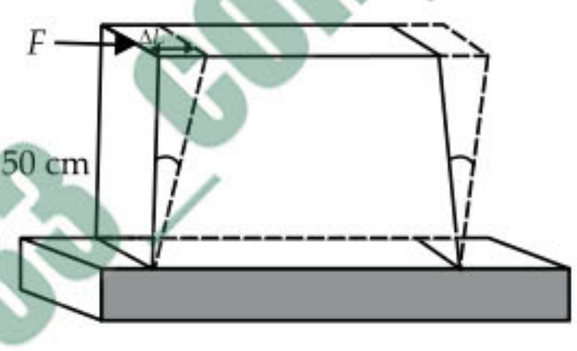
$$Y = \frac{F/\pi(D/2)^2}{\Delta L/L} = \frac{4FL}{\pi D^2 L}$$

As per the conditions of the problem, F(tension), length L, and extension DL is same for each wire.

$$\therefore \quad Y \propto \frac{1}{D^2} \text{ or } D \propto \sqrt{\frac{1}{Y}}$$

$$\therefore \quad \frac{D_{\text{copper}}}{D_{\text{iron}}} = \sqrt{\frac{Y_{\text{iron}}}{Y_{\text{copper}}}}$$

23. (a) : The lead slab is fixed and force is applied parallel to the narrow face as shown in the figure.



Area of the face parallel to which this force is applied is

$A = 50\,\text{cm} \times 10\,\text{cm}$

$= 0.5\,\text{m} \times 0.1\,\text{m} = 0.05\,\text{m}^2$

If ΔL is the displacement of the upper edge of the slab due to tangential force F, then

$$\eta = \frac{F/A}{\Delta L/L} \text{ or } \Delta L = \frac{\eta L}{YA}$$

Substituting the given values, we get

$$\Delta L = \frac{(9 \times 10^4\,\text{N})\,(0.5\,\text{m})}{5.6 \times 10^9\,\text{N m}^{-2} \times 0.05\,\text{m}^2}$$

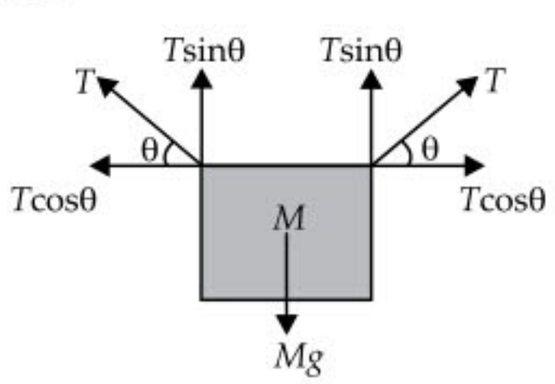
$$= 1.6 \times 10^{-4}\,\text{m} = 0.16\,\text{mm}$$

24. (c) : Let M be the mass of rectangular frame and θ be the angle which the tension T in the string make with the horizontal. Refer figure, then

$$2T\sin\theta = Mg$$

$$\text{or} \quad T = \frac{Mg}{2\sin\theta}$$

$$\text{or} \quad T \propto \frac{1}{\sin\theta}$$



T is least if $\sin\theta$ has maximum value *i.e.*, $\sin\theta = 1 = \sin 90°$. Thus option (c) is correct.

25. (a) : As $\Delta l = \frac{Fl}{AY}$

$$\text{or} \quad \frac{\Delta l}{l} = \left(\frac{F}{AY}\right)$$

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Potential energy per unit volume

$$= \frac{1}{2} \times \text{stress} \times \text{strain}$$

$$U = \frac{1}{2} \times \frac{F}{A} \times \frac{F}{AY} \quad \text{or} \quad U \propto \frac{1}{A^2} \quad \text{or} \quad U \propto \frac{1}{d^4}$$

$$\therefore \quad \frac{U_1}{U_2} = \left(\frac{d_2}{d_1}\right)^4 = \frac{16}{1} \qquad \left(\text{Given, } \frac{d_2}{d_1} = \frac{2}{1}\right)$$

26. (b) : For most materials, the modulus of rigidity is one-third of the Young's modulus.

$$\eta = \frac{1}{3} Y \quad \text{or} \quad Y = 3\eta$$

$$\therefore \quad n = 3$$

27. (c) : For copper wire, $L_C = 3.5$ m,
$A_C = 4 \times 10^{-5}$ m^2
For steel wire, $L_S = 4.5$ m,
$A_S = 3 \times 10^{-5}$ m^2

As Young's modulus, $Y = \dfrac{(F/A)}{(\Delta L/L)}$

As applied force F and extension ΔL are same for steel and copper wires

$$\therefore \quad \frac{F}{\Delta L} = \frac{Y_S A_S}{L_S} = \frac{Y_C A_C}{L_C}$$

where the subscripts C and S refers to copper and steel respectively.

$$\therefore \quad \frac{Y_S}{Y_C} = \frac{L_S}{L_C} \times \frac{A_C}{A_S}$$

$$= \frac{(4.5 \text{ m}) \times (4 \times 10^{-5} \text{ m}^2)}{(3.5 \text{ m}) \times (3 \times 10^{-5} \text{ m}^2)} = 1.7$$

28. (c) : When a spring is stretched by applying a load to its free end, both longitudinal and shear strain are produced in the spring.

29. (d) : The Young's modulus of elasticity decreases with rise in temperature.

30. (c) : Let h be the depth at which the rubber ball be taken. Then

$$P = h\rho g$$

By definition of bulk modulus,

$$B = -\frac{P}{\Delta V / V}$$

The negative sign shows that with increase in pressure, a decrease in volume occurs.

$$\therefore \quad P = B\frac{\Delta V}{V}$$

Using (i),

$$\text{or} \quad h\rho g = B\frac{\Delta V}{V} \quad h = \frac{B}{\rho g}\frac{\Delta V}{V}$$

Substituting the given values, we get

$$h = \frac{9 \times 10^8 \text{ N m}^{-2}}{10^3 \text{ kg m}^{-3} \times 10 \text{ m s}^{-2}} \left(\frac{0.1}{100}\right) = 90 \text{ m}$$

31. (b) : Solids are least compressible whereas gases are most compressible. Gases are about a million times compressible than solids.
All other statements are correct.

32. (d) : Substances like tissue of aorta, rubber etc. which can be stretched to cause large strains are called elastomers.

33. (a) : A bar of length l, breadth b, and depth d when loaded at the centre by a load W sags by an amount given by

$$\delta = \frac{Wl^3}{4bd^3Y}$$

34. (c) : The shear modulus is also known as modulus of rigidity.

35. (b) : In case of shearing stress there is a change in shape without any change in volume. In case of hydraulic stress there is a change in volume without any change in shape.

36. (a) : Using, $\Delta L = \dfrac{FL}{YA} = \dfrac{(LA\rho g)\frac{L}{2}}{YA}$

($\because$ Weight of wire acts at its centre of mass, *i.e.*, $L \to \frac{L}{2}$).

$$\therefore \quad \Delta L = \frac{L^2 A\rho g}{2YA} = \frac{L^2 \rho g}{2Y}$$

$$= \frac{8^2 \times 1.5 \times 10^3 \times 10}{2 \times 5 \times 10^6} = 9.6 \times 10^{-2} \text{ m}$$

37. (c)

38. (b) : Young's modulus, $Y = \dfrac{Fl}{A\Delta l}$

$$\text{or} \quad \Delta l = \frac{Fl}{AY} \; ; \; \frac{\Delta l_S}{\Delta l_B} = \frac{F_S}{F_B} \times \frac{l_S}{l_B} \times \frac{A_B}{A_S} \times \frac{Y_B}{Y_S}$$

$$\text{or} \quad \frac{\Delta l_S}{\Delta l_B} = \left(\frac{3\,mg}{2\,mg}\right) \times a \times \frac{1}{b^2} \times \frac{1}{c} = \frac{3a}{2\,b^2 c}$$

39. (d) : Given, Poisson's ratio = 0.5. It shows that the density of material is constant. Therefore, the change in volume of the wire is zero. Thus

$V = A \times l$ = a constant

$\log V = \log A + \log l$

$$\therefore \quad \frac{\Delta V}{V} = \frac{\Delta A}{A} + \frac{\Delta l}{l} = 0 \quad \text{or} \quad \frac{\Delta l}{l} = -\frac{\Delta A}{A}$$

or % increase in length $= \dfrac{\Delta l}{l} \times 100 = -(-4) = 4\%$

40. (b) : Increase in length due to rise in temperature is

$\Delta l = l\,\alpha\,100$

or $\Delta l/l = \alpha \times 100$ ...(i)

$$Y = \frac{F}{A} \times \frac{l}{\Delta l} \text{ or } F = YA\frac{\Delta l}{l} = YA \times \alpha \times 100 \qquad \text{(Using (i))}$$

Thus F is independent of l.

41. (b) : For steel wire,
$L_S = 1.5$ m, $Y_S = 2 \times 10^{11}$ N m^{-2}

$$r_S = \frac{0.25}{2} \text{ cm} = 0.125 \times 10^{-2} \text{ m}$$

The stretching force for the steel wire is

$F_S = (4 + 6)g = 10g$ N

$$\text{As } Y = \frac{FL}{A\Delta L} = \frac{FL}{\pi r^2 \Delta L}$$

$$\therefore \quad \Delta L = \frac{FL}{\pi r^2 Y}$$

$$\therefore \quad \Delta L_S = \frac{F_S L_S}{\pi r_S^2 Y_S}$$

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For brass wire,

$L_B = 1$ m, $Y_B = 1 \times 10^{11}$ N m^{-2}

$$r_B = \frac{0.25}{2}\text{cm} = 0.125 \times 10^{-2} \text{ m}$$

The stretching force the brass wire is

$F_B = 6g$ N

$$\therefore \quad \Delta L_B = \frac{F_B L_B}{\pi r_B^2 Y_B}$$

Their corresponding ratio is

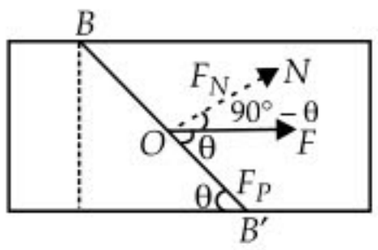
$$\frac{\Delta L_S}{\Delta L_B} = \frac{F_S}{F_B}\frac{L_S}{L_B}\frac{r_B^2}{r_S^2}\frac{Y_B}{Y_S}$$

Substituting the given values, we get

$$= \frac{10g}{6g} \times \frac{1.5}{1} \times \frac{0.125 \times 10^{-2}}{0.125 \times 10^{-2}} \times \frac{1 \times 10^{11}}{2 \times 10^{11}}$$

$$= \frac{5}{4}$$

42. (a) : Consider the equilibrium of the plane BB'. A force F must be acting on this plane making an angle $(90° - \theta)$ with the normal ON. Resolving F into two components, along the plane and normal to the plane.



Component of force F along the plane,

$\therefore \quad F_P = F\cos\theta$

Component of force F normal to the plane,

$F_N = F\cos(90° - \theta) = F\sin\theta$

Let the area of the face BB' be A'. Then

$$\frac{A}{A'} = \sin\theta$$

$$\therefore \quad A' = \frac{A}{\sin\theta}$$

$$\therefore \quad \text{Tensile stress} = \frac{F\sin\theta}{A'} = \frac{F}{A}\sin^2\theta$$

$$\text{Shearing stress} = \frac{F\cos\theta}{A'}$$

$$= \frac{F}{A}\cos\theta\sin\theta = \frac{F\sin 2\theta}{2A}$$

Their corresponding ratio is

$$\frac{\text{Tensile stress}}{\text{Shearing stress}} = \frac{F}{A}\sin^2\theta \times \frac{A}{F\sin\theta\cos\theta} = \tan\theta$$

43. (c) : Shearing stress $= \dfrac{F\sin 2\theta}{2A}$

Shearing stress is maximum when $\sin 2\theta = 1$

or $\sin 2\theta = \sin 90°$ or $2\theta = 90°$

or $\theta = 45°$

44. (b) : If the ultimate tensile strength and fracture points are close, the material is said to be brittle. Hence, material B is more brittle than material A.

45. (c) : Radius of a rivet,

$$r = \frac{6}{2} \text{ mm} = 3 \text{ mm} = 3 \times 10^{-3} \text{ m}$$

Maximum stress $= 6.9 \times 10^7$ Pa

Maximum load on a rivet

= Maximum stress × Area of cross-section

$= 6.9 \times 10^7 \times \pi \times (3 \times 10^{-3})^2$

$= 1950$ N

$\therefore$ Maximum tension that can be exerted by rivet strip

$= 4 \times 1950 \text{ N} = 7.8 \times 10^3$ N

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Mechanical Properties of Fluids

Pressure

Thrust : The total normal force exerted by liquid at rest on a given surface in contact with it is called thrust of liquid on that surface.

Pressure : It is defined as the thrust acting per unit area of the surface in contact with liquid.

$$P = \frac{\text{Thrust } (F)}{\text{Area } (A)} = \frac{F}{A}$$

Pressure is a scalar quantity. Its dimensional formula is $[ML^{-1}T^{-2}]$.

The SI unit of pressure is N m^{-2}. It has been named as pascal (Pa) in the honour of French scientist Blaise Pascal.

Other common units of pressure are :

- 1 atm = 1.01×10^5 Pa
- 1 bar = 10^5 Pa
- 1 torr = 133 Pa
- 1 mm of Hg = 1 torr = 133 Pa.

Viscosity

When a fluid flows such that a velocity gradient is set up within it, force act within the fluid so as to prevent the velocity gradient from existing. This force is due to the property called viscosity.

Thus, $F = -\eta A \frac{dv}{dz}$

The negative sign is put to account for the fact that the viscous force is opposite to the direction of motion.

Where η is a constant called coefficient of viscosity, its CGS unit is poise. Dimension is $[ML^{-1}T^{-1}]$. The SI unit of viscosity is poiseuille (Pl).

1 Pl = 10 poise

Effect on viscosity

- **Effect of temperature :** On increasing temperature viscosity of a liquid decreases.
- **Effect of pressure :** On increasing pressure viscosity of liquid increases but viscosity of water decreases.

Stoke's Law

When a sphere of radius r moves with a velocity v through a fluid of viscosity η, the viscous force opposing the motion of the sphere is given by

$F = 6\pi\eta rv$

Importance of stoke's law

- This law is used in the determination of electronic charge with the help of milikan's experiment.
- This law accounts the formation of clouds.
- This law accounts why the speed of rain drops is less than that of a body falling freely with a constant velocity from the height of clouds.
- This law helps a man coming down with the help of parachute.

Terminal velocity

If for a sphere, viscous force become equal to the net weight acting downward, the velocity of the body become constant and is known as terminal velocity and is given by,

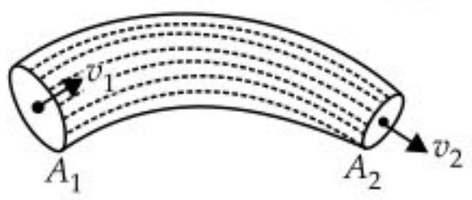
$$v_t = \frac{2}{9} r^2 \left(\frac{\rho - \sigma}{\eta} \right) g$$

Streamline Flow

When a liquid (fluid) flows, such that each particle of the liquid passing a point moves along the same path and has the velocity as its predecessor then the flow is called streamline flow. It is also called laminar flow.

Equation of continuity

If an incompressible and non-viscous liquid flowing through a tube of non-uniform cross-section with steady flow, the product of the area of cross-section and the velocity of flow remains same at every point in the tube.



$A_1v_1 = A_2v_2$

Av = constant.

This equation is known as continuity equation.

- In the steady flow of an incompressible liquid mass of the liquid flowing per second through a cross section of the tube is constant.

  i.e. $Av\rho$ = a constant.
- In a streamline flow, the volume of the liquid flowing per second through a cross section of the tube = Av where A is the area of cross section and v is the velocity of the liquid flowing over that cross-section.

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- The equation of continuity represents the conservation of mass in case of moving fluids.
- In case a non-viscous liquid is moving with streamline flow, the velocity of liquid flow is independent of the nature of liquid.
- In a steady flow through a varying tube, the velocity of flow will increase where area of cross-section of tube decreases and vice versa.

Turbulent flow

When the velocity at a point in the liquid changes with time the flow is called unsteady flow. The unsteady flow is called turbulent when there are bends in the path of a fast moving liquid.

Critical velocity

The critical velocity is that velocity of liquid flow, upto which its flow is streamlined and above which its flow becomes turbulent.

$$v_c = \frac{k\eta}{\rho r}$$

Reynold number

Reynold number is a pure number which determines the nature of flow of liquid through a pipe. According to Reynold, the critical velocity v_c of a liquid flowing through a tube of diameter D is given by

$$v_c = \frac{N_R \eta}{\rho D} \quad \text{or} \quad N_R = \frac{\rho D v_c}{\eta}$$

Where η is the coefficient of viscosity of the liquid, r is the density of liquid and N_R is a constant called Reynold number.

If the value of Reynold number lies between 0 to 2000, the flow of liquid is streamline or laminar. For values of N_R above 3000, the flow of liquid is turbulent and for values of N_R between 2000 to 3000, the flow of liquid is unstable changing from streamline to turbulent flow.

Bernoulli's Theorem

It states that in a streamline flow of incompressible and non-viscous fluid through a tube of non-uniform cross-section, the sum of the pressure energy per unit volume, the potential energy per unit volume and the kinetic energy per unit volume is same at every point in the tube,

i.e., $P + \rho g h + \frac{1}{2}\rho v^2 = \text{constant}$

This equation is known as Bernoulli's equation. It represents conservation of mechanical energy in case of moving fluids.

If the liquid is flowing through a horizontal tube, then h is constant, then Bernoulli's theorem states that

$$P + \frac{1}{2}\rho v^2 = \text{a constant}$$

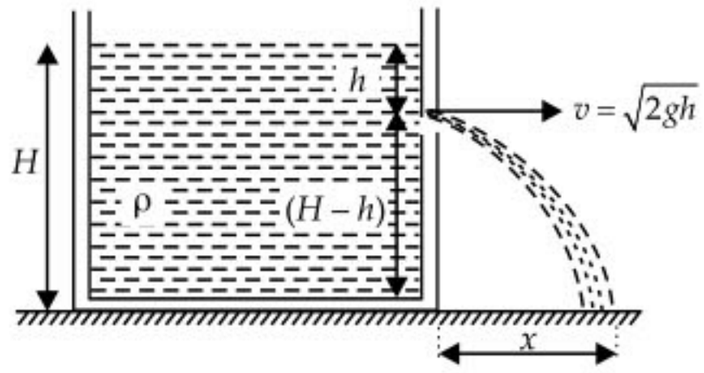
Applications of Bernoulli's theorem

- Bunsen's burner
- Atomiser or sprayer
- Aerofoil or lift on aircraft wing
- Blowing off the roof during storm
- **Curved motion of a spinning ball (Magnus effect):** When a spinning ball is thrown, it deviates from its usual path in flight. This effect is called magnus effect. This effect also occurs in accordance with Bernoulli's theorem.
- **Venturimeter :** It is a device used for measuring the speed of incompressible liquid and rate of flow of liquid through pipes. Its working is based upon Bernoulli's theorem.

Torricelli's Theorem

- It states that velocity of efflux *i.e.* the velocity with which the liquid flows out of an orifice (*i.e.* a narrow hole) is equal to that which a freely falling body would acquire in falling through a vertical distance equal to the depth of the orifice below the free surface of liquid.

  Velocity of efflux, $v = \sqrt{2gh}$.
- The velocity of efflux *i.e.*, velocity of liquid coming out of the orifice is independent of
  - the nature of liquid
  - the quantity of liquid in the vessel
  - the area of the orifice.



- Time taken by liquid to reach the base level,

$$t = \sqrt{\frac{2(H-h)}{g}}.$$

- Range of a liquid flowing out from the orifice is

$$x = vt = \sqrt{2gh} \times \sqrt{[2(H-h)/g]} = 2\sqrt{h(H-h)}.$$

  This range will be maximum when $H = 2h$
- If the hole is at the bottom of the tank, time t taken by the tank to be emptied,

$$t = \frac{A}{A_0}\sqrt{\frac{2H}{g}}$$

  where A_0 is the area of orifice or hole and A that of the vessel.

Surface Tension

The free surface of a liquid contracts so that its exposed surface area becomes minimum *i.e.*, it behave as if it were under tension, some what like a stretched elastic membrane. This property is known as surface tension.

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The surface tension of a liquid varies with temperature as well as dissolved impurities, etc. When soap is mixed with water, the surface tension of water decreases.
Surface tension of a liquid is measured by the normal force acting per unit length.

i.e., $S = \frac{F}{L}$.

Properties of surface tension

- Scalar quantity
- Temperature sensitive
- Impurity sensitive
- Depends only on the nature of liquid.
- SI unit of surface tension is N m^{-1}
- Dimensions of surface tension is $[ML^0T^{-2}]$.

Surface energy

It is defined as the amount of work done against the force of surface tension in increasing the liquid surface of a given area at a constant temperature.
i.e., surface energy = work done = surface tension × increase in surface area of the liquid
The SI unit of surface energy is joule and CGS unit is erg.
When a bigger drop splits into smaller drops, energy is required to break it but when smaller drops coalesce to form a bigger drop energy is released.
Work done in forming a liquid drop of radius r, surface tension S is, $W = 4\pi r^2 S$.
Work done in forming a soap bubble of radius r, surface tension S is,

$$W = 2 \times 4\pi r^2 S = 8\pi r^2 S$$

Work done in increasing the radius of a liquid drop from r_1 to r_2 is

$$W = 4\pi S\left(r_2^2 - r_1^2\right)$$

Work done in increasing the radius of a soap bubble from r_1 to r_2 is

$$W = 8\pi S\left(r_2^2 - r_1^2\right)$$

When n number of smaller drops of a liquid, each of radius r, surface tension S are combined to form a bigger drop of radius R, then

$$R = n^{1/3} r$$

The surface area of bigger drop = $4\pi R^2 = 4\pi n^{2/3} r^2$. It is less than the area of n smaller drops.
Work done in breaking a liquid drop of radius R into n equal small drops

$$W = 4\pi R^2 (n^{1/3} - 1)S$$

where S is the surface tension.

Excess pressure

The pressure on the concave side of the liquid surface is always greater than the pressure on the convex side. The difference of pressure is known as excess pressure.

Excess pressure inside a liquid drop is given by $P = \frac{2S}{r}$

Excess pressure inside a soap bubble is given by $P = \frac{4S}{r}$.

Excess pressure inside an air bubble in a liquid is given by $P = \frac{2S}{r}$

When an air bubble of radius r is at depth h below the free surface of liquid of density ρ and surface tension S, then the excess pressure inside the bubble,

$$P = \frac{2S}{r} + h\rho g$$

If r_1 and r_2 are the radii of curved liquid surface, then excess pressure inside the liquid surface is given by

$$P = S\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

When two bubbles of different sizes are in communication with each other, air passes from smaller one to larger one and larger one grows at the expense of smaller one. This happens due to pressure inside the smaller bubble being higher than that inside the larger bubble.

- When two soap bubbles of radii r_1 and r_2 coalesce to form a new soap bubble of radius r, under isothermal conditions then,

$$r = \sqrt{r_1^2 + r_2^2}$$

- When two soap bubbles of radii r_1 and r_2 are in contact with each other and r is the radius of the interface, then

$$r = \frac{r_1 r_2}{r_2 - r_1}$$

- The total pressure inside an air bubble of radius r at a depth h below the surface of liquid of density ρ is

$$P = P_0 + h\rho g + \frac{2S}{r}$$

where P_0 is the atmospheric pressure and S is the surface tension of liquid.
If a small drop of water is squeezed between two parallel glass plates so that a very thin layer of large area is formed then the pressure inside the water layer is less than the pressure on the plates by $(2S/d)$ (where d is the distance between the plates).

Angle of contact

It is defined as the angle between the tangents to solid and liquid surfaces at a point of contact inside the liquid. It depends on the nature of solid and liquid.

- The angle of contact is different for different pairs of solids and liquids.
- Angle of contact does not depend upon the inclination of the solid surface to the liquid surface.
- Angle of contact increases with increase in temperature of liquid.
- Angle of contact decreases on adding soluble impurity to a liquid.

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- The value of angle of contact lies between 0° and 180°. The value of angle of contact for pure water and glass (without grease) is zero.
- For all those liquids which wet the solid surface and which rise up in a capillary tube, the angle of contact is an acute angle ($\theta < 90°$), e.g. water and glass.
- For all those liquids which do not wet a solid surface and which depress in a capillary tube, the angle of contact is an obtuse angle ($\theta > 90°$). e.g. glass and mercury.
- For all those liquids which neither rise nor get depressed in a capillary tube, the angle of contact is right angle ($\theta = 90°$). *e.g.* silver, and water.

Capillarity

The phenomenon of rise or fall of liquid in a capillary tube is known as capillarity.

The rise or fall in a capillary tube is given by

$$h = \frac{2S\cos\theta}{r\rho g} = \frac{2S}{R\rho g} \qquad \left(\because \cos\theta = \frac{r}{R}\right)$$

where S is the surface tension of the liquid, θ is the angle of contact, ρ is the density of liquid, r is the radius of capillary tube, R is the radius of the meniscus and g is the acceleration due to gravity.

- If $\theta > 90°$, *i.e.*, meniscus is convex, h will be negative, *i.e.*, the liquid will fall in a capillary tube.
- If $\theta = 90°$, *i.e.*, meniscus is plane, $h = 0$, so no phenomenon of capillarity.
- If $\theta < 90°$, *i.e.*, meniscus is concave, h will be positive, *i.e.*, the liquid will rise in the capillary.

If a capillary tube is of insufficient length as compared to height to which liquid can rise in the capillary tube, then the liquid rises upto the full length of capillary tube but there is no overflowing of the liquid in the form of fountain. It is so because the liquid meniscus adjusts its radius of curvature so that hR = a constant *i.e.* $hR = h'R'$.

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EXAM DRILL

1. A piece of solid weighs 120 g in air, 80 g in water and 60 g in a liquid. The relative density of the solid and that of the liquid are respectively

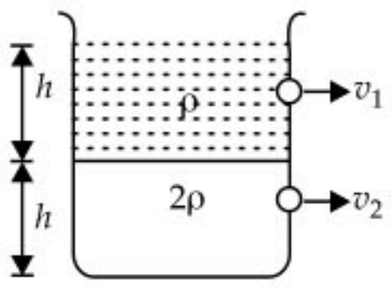
(a) 3, 2 (b) $2, \frac{3}{4}$

(c) $\frac{3}{2}, 2$ (d) $3, \frac{3}{2}$

2. Bernoulli's equation for steady, non-viscous, incompressible flow expresses the

(a) conservation of angular momentum
(b) conservation of density
(c) conservation of momentum
(d) conservation of energy

3. Equal volume of two immiscible liquids of densities ρ and 2ρ are filled in a vessel as shown in figure. Two small holes are punched at depths $\frac{h}{2}$ and $\frac{3h}{2}$ from the surface of lighter liquid. If v_1 and v_2 are the velocities of efflux at these two holes. Then $\frac{v_1}{v_2}$ is



(a) $\frac{1}{2\sqrt{2}}$ (b) $\frac{1}{2}$ (c) $\frac{1}{4}$ (d) $\frac{1}{\sqrt{2}}$

4. A body of density D_1 and mass M is moving downwards in glycerine of density D_2. What is the viscous force acting on it?

(a) $Mg\left(1-\frac{D_2}{D_1}\right)$ (b) $Mg\left(1-\frac{D_1}{D_2}\right)$

(c) MgD_1 (d) MgD_2

5. An object of weight W and density ρ is submerged in a fluid of density ρ_1. Its apparent weight will be

(a) $W(\rho-\rho_1)$ (b) $\frac{(\rho-\rho_1)}{W}$

(c) $W\left(1-\frac{\rho_1}{\rho}\right)$ (d) $W(\rho_1-\rho)$

6. A spherical solid ball of volume V is made of a material of density ρ_1. It is falling through a liquid of density ρ_2 ($\rho_2 < \rho_1$). Assume that the liquid applies a viscous force on the ball that is proportional to the square of its speed v, *i.e.*, $F_{viscous} = -kv^2$ ($k > 0$). The terminal speed of the ball is

(a) $\frac{Vg(\rho_1-\rho_2)}{k}$ (b) $\sqrt{\frac{Vg(\rho_1-\rho_2)}{k}}$

(c) $\frac{Vg\rho_1}{k}$ (d) $\sqrt{\frac{Vg\rho_1}{k}}$

7. If a sample of metal weighs 210 gram in air, 180 gram in water and 120 gram in a liquid, then

(a) relative density of liquid is 3
(b) relative density of liquid is $\left(\frac{1}{3}\right)$
(c) relative density of metal is 8
(d) relative density of metal is 3

8. If two capillary tubes of radii r_1 and r_2 in the ratio 1 : 2 are dipped vertically in water, then the ratio of capillary rises in the respective tubes is

(a) 1 : 4 (b) 4 : 1
(c) 1 : 2 (d) 2 : 1

9. If the excess pressure inside a soap bubble of radius r_1 in air is equal to the excess pressure inside air bubble of radius r_2 inside the soap solution, then $r_1 : r_2$ is

(a) 2 : 1 (b) 1 : 2
(c) 1 : 4 (d) $\sqrt{2}$: 1

10. The pressure at depth h below the surface of a liquid of density ρ open to the atmosphere is

(a) greater than the atmospheric pressure by ρgh
(b) less than the atmospheric pressure by ρgh
(c) equal to the atmospheric pressure
(d) decreases exponentially with depth

11. A body is floating in liquid with 50% of its volume outside the liquid. When the entire system accelerates upwards with an acceleration $g/3$, the percentage of its volume outside the liquid is

(a) 33% (b) 50%
(c) 25% (d) 66%

12. An object floats in water with 10% of its volume outside and in oil 30% of its volume outside. The specific gravity of the oil is

(a) 1.3 (b) 0.33
(c) 2 (d) 7

13. The force acting on a window of area 50 cm × 50 cm of a submarine at a depth of 2000 m in an ocean, interior of which is maintained at sea level atmospheric pressure is (Density of sea water = 10^3 kgm^{-3}, $g = 10$ ms^{-2})

(a) 10^6 N (b) 5×10^5 N
(c) 25×10^6 N (d) 5×10^6 N

14. The rise in the water level in a capillary tube of radius 0.07 cm when dipped vertically in a beaker containing water of surface tension 0.07 Nm^{-1} is ($g = 10$ ms^{-2})

(a) 2 cm (b) 4 cm
(c) 1.5 cm (d) 3 cm

15. A hole is in the bottom of the tank having water. If total pressure at the bottom is 3 atm. (1 atm = 10^5 N m^{-2}), then velocity of water flowing from hole is

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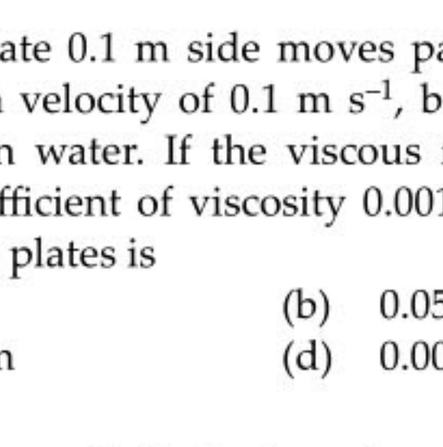
(a) $\sqrt{400}$ m s^{-1} (b) $\sqrt{600}$ m s^{-1}
(c) $\sqrt{60}$ m s^{-1} (d) $\sqrt{300}$ m s^{-1}

16. Spheres of iron and lead having same mass are completely immersed in water. Density of lead is more than that of iron. Apparent loss of weight is W_1 for iron sphere and W_2 for lead sphere. Then $\frac{W_1}{W_2}$ is
(a) = 1 (b) between 0 and 1
(c) = 0 (d) > 1

17. Water rises in plant fibres due to
(a) capillarity (b) viscosity
(c) fluid pressure (d) osmosis

18. A mosquito with 8 legs stands on water surface and each leg makes depression of radius a. If the surface tension and angle of contact are T and zero respectively, then the weight of mosquito is
(a) $8Ta$ (b) $16\pi Ta$
(c) $\frac{Ta}{8}$ (d) $\frac{Ta}{16\pi}$

19. The figure shows a soap film in which a closed elastic thread is lying. The film inside the thread is pricked. Now the sliding wire is moved out so that the surface area increases. The radius of the circle formed by elastic thread will



(a) increase (b) decrease
(c) remains same (d) data insufficient

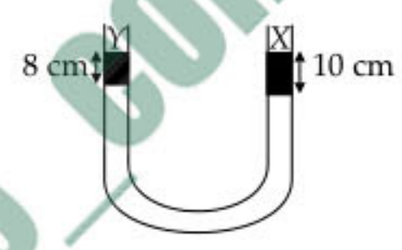
20. When a ball is released from rest in a very long column of viscous liquid, its downward acceleration is a(just after release). Find its acceleration when it has acquired two third of the maximum velocity.
(a) $\frac{a}{3}$ (b) $\frac{2}{3}a$
(c) $\frac{a}{6}$ (d) None of these

21. A square plate 0.1 m side moves parallel to second plate with a velocity of 0.1 m s^{-1}, both plates being immersed in water. If the viscous force is 0.002 N and the coefficient of viscosity 0.001 poise, distance between the plates is
(a) 0.1 m (b) 0.05 m
(c) 0.005 m (d) 0.0005 m

22. A block of wood floats in water with $\left(\frac{4}{5}\right)^{\text{th}}$ of its volume submerged. If the same block just floats in a liquid, the density of the liquid (in kg m^{-3}) is
(a) 1250 (b) 600
(c) 400 (d) 800

23. A capillary tube is taken from the earth to the surface of the moon. The rise of the liquid column on the moon is
(Acceleration due to gravity on the earth is 6 times that of the moon)
(a) six times that on the earth's surface
(b) $\frac{1}{6}$ that on the earth's surface
(c) equal to that on the earth's surface
(d) zero

24. A liquid X of density 3.36 g cm^{-3} is poured in a U-tube, which contains Hg. Another liquid Y is poured in left arm with height 8 cm, upper levels of X and Y are same. What is the density of Y?

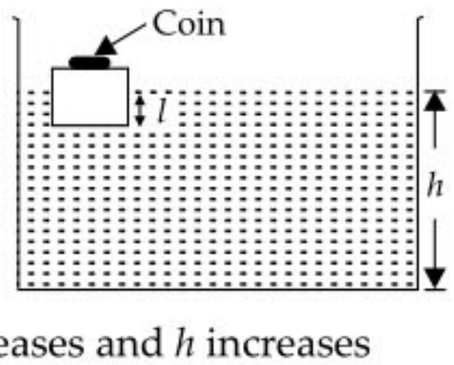


(a) 0.8 g cm^{-3} (b) 1.2 g cm^{-3}
(c) 1.4 g cm^{-3} (d) 1.6 g cm^{-3}

25. A solid sphere falls with a terminal velocity v in CO_2 gas. If it is allowed to fall in vacuum,
(a) terminal velocity of sphere = v
(b) terminal velocity of sphere < v
(c) terminal velocity of sphere > v
(d) sphere never attains terminal velocity

26. Water is conveyed through a uniform tube of 8 cm in diameter and 3140 m in length at the rate 2×10^{-3} m^3 per second. The pressure required to maintain the flow is
(Viscosity of water = 10^{-3} SI units)
(a) 6.25×10^3 N m^{-2} (b) 0.625 N m^{-2}
(c) 0.0625 N m^{-2} (d) 0.00625 N m^{-2}

27. A wooden block, witha coin placed on its top, floats in water as shown in figure. The distances l and h are shown there. After some time the coin falls into the water. Then



(a) l decreases and h increases
(b) l increases and h decreases
(c) both l and h increase
(d) both l and h decrease

28. By sucking through a straw, a student can reduce the pressure in his lungs to 750 mm of Hg (density = 13.6 g cm^{-3}). Using the straw, he can drink water from a glass upto maximum depth of
(a) 10 cm (b) 75 cm
(c) 13.6 cm (d) 1.36 cm

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29. What is the ratio of surface energy of 1 small drop and 1 large drop if 1000 drops combined to form 1 large drop?
(a) 100 : 1 (b) 1000 : 1
(c) 10 : 1 (d) 1 : 100

30. Water in a river 20 m deep is flowing at a speed of 10 m s^{-1}. The shearing stress between the horizontal layers of water in the river in N m^{-2} is
(Coefficient of viscosity of water = 10^{-3} SI units)
(a) 1×10^{-2} (b) 0.5×10^{-2}
(c) 1×10^{-3} (d) 0.5×10^{-3}

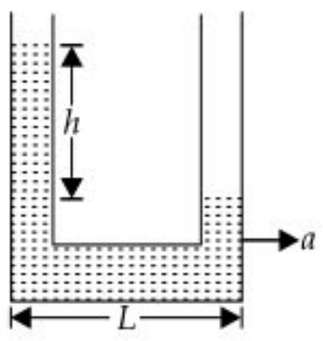
31. A glass capillary tube of inner diameter 0.28 mm is lowered vertically into water in a vessel. The pressure to be applied on the water in the capillary tube so that water level in the tube is same as that in the vessel in N m^{-2} is (Surface tension of water = 0.07 Nm^{-1} and atmospheric pressure = 10^5 N m^{-2})
(a) 10^3 (b) 99×10^3
(c) 100×10^3 (d) 101×10^3

32. The level of water in a tank is 5 m high. A hole of area 10 cm^2 is made in the bottom of the tank. The rate of leakage of water from the hole is (Take $g = 10$ m s^{-2})
(a) 10^{-2} m^3 s^{-1} (b) 10^{-3} m^3 s^{-1}
(c) 10^{-4} m^3 s^{-1} (d) 10^3 m^3 s^{-1}

33. A wooden ball of density ρ is immersed in water of density ρ_0 to depth h and then released. The height above the surface of water upto which the ball jump out of water is
(a) zero (b) h
(c) $\frac{\rho_0 h}{\rho}$ (d) $\left(\frac{\rho_0}{\rho} - 1\right)h$

34. Tanks A and B open at the top contain two different liquids upto certain height in them. A hole is made to the wall of each tank at a depth h from the surface of the liquid. The area of the hole in B is twice that of in A. If the liquid mass flux through each hole is equal, then the ratio of the densities of the liquids respectively, is
(a) 2 (b) $\frac{3}{2}$
(c) $\frac{2}{3}$ (d) $\frac{1}{2}$

35. When at rest, a liquid stands at the same level in the tubes shown in figure. But as indicated, a height difference h occurs when the system is given an acceleration a towards the right. Here h is equal to



(a) $\frac{aL}{2g}$ (b) $\frac{gL}{2a}$
(c) $\frac{gL}{a}$ (d) $\frac{aL}{g}$

36. An aeroplane of mass 3×10^4 kg and total wing area of 120 m^2 is in a level flight at some height. The difference in pressure between the upper and lower surface of its wings is
(a) 2.5 kPa (b) 5.0 kPa
(c) 10.0 kPa (d) 12.5 kPa

37. A block of steel of size 5 cm × 5 cm × 5 cm is weighed in water. If the relative density of steel is 7, its apparent weight is
(a) $5 \times 5 \times 5 \times 6 \times g$ (b) $4 \times 4 \times 4 \times 7 \times g$
(c) $5 \times 5 \times 5 \times 7 \times g$ (d) $5 \times 5 \times 5 \times 4 \times g$

38. A water barrel having water up to a depth d is placed on a table of height h. A small hole is made on the wall of the barrel at its bottom. If the stream of water coming out of the hole falls on the ground at a horizontal distance R from the barrel, then the value of d is
(a) $\frac{4h}{R^2}$ (b) $4hR^2$
(c) $\frac{R^2}{4h}$ (d) $\frac{h}{4R^2}$

39. In English, the phrase 'tip of the iceberg' is used to mean a small visible fraction of something that is mostly hidden. For a real iceberg, what is this fraction if the density of sea water is 1.03 g cm^{-3} and that of ice is 0.92 g cm^{-3}?
(a) 0.106 (b) 10.6
(c) 0.901 (d) 0.801

40. Two vessels have base areas in the ratio 1 : 4. They are filled with water to the same height. If the amount of water in one be 4 times that in the other, then the ratio of pressure on their bottoms will be
(a) 16 : 1 (b) 8 : 1
(c) 4 : 1 (d) 1 : 1

41. In Millikan's oil drop experiment, a charged oil drop of mass 3.2×10^{-14} kg is held stationary between two parallel plates 6 mm apart, by applying a potential difference of 1200 V between them. How many electrons does the oil drop carry? (Take $g = 10$ m s^{-2})
(a) 7 (b) 8
(c) 9 (d) 10

42. For turbulent flow, the value of Reynolds number is
(a) $R_e < 2000$ (b) $R_e > 2000$
(c) $1000 < R_e < 2000$ (d) $R_e = 1000$

43. Water rises in a capillary tube to a height of 2.0 cm. In another capillary tube whose radius is one third of it, how much the water will rise?
(a) 5 cm (b) 3 cm
(c) 6 cm (d) 9 cm

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44. A rectangular vessel when full of water, takes 10 min to be emptied through an orifice in its bottom. How much time will it take to be emptied when half filled with water?

(a) 9 min
(b) 7 min
(c) 5 min
(d) 3 min

45. A garden hose having an internal diameter 2.0 cm is connected to a lawn sprinkler that consists of an enclosure with 24 holes, each 0.125 cm in diameter. If water in the hose has a speed of 90.0 cm s^{-1}, find the speed of the water having the sprinkler hole.

(a) 860 cm s^{-1} (b) 960 cm s^{-1}
(c) 760 cm s^{-1} (d) 660 cm s^{-1}

DAY 09 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ◉

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____

(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (d) : Relative density of solid

$$= \frac{\text{Weight in air}}{\text{Weight in air} - \text{Weight in water}} = \frac{120}{120-80} = \frac{120}{40} = 3$$

Relative density of liquid

$$= \frac{\text{Weight in air} - \text{Weight in liquid}}{\text{Weight in air} - \text{Weight in water}} = \frac{120-60}{120-80} = \frac{60}{40} = \frac{3}{2}$$

2. (d)

3. (d) : $v_1 = \sqrt{2g\left(\frac{h}{2}\right)} = \sqrt{gh}$

Using Bernoulli's theorem, we get

$$P_a + \rho g h + 2\rho g\left(\frac{h}{2}\right) = P_a + \frac{1}{2}(2\rho)v_2^2$$

or $v_2 = \sqrt{2gh}$ $\quad \therefore \quad \frac{v_1}{v_2} = \frac{1}{\sqrt{2}}$

4. (a) : Volume of the body $= \frac{M}{D_1}$

Mass of liquid displaced by the body

$$M' = \left(\frac{M}{D_1}\right)D_2$$

Viscous force = Effective weight of the body

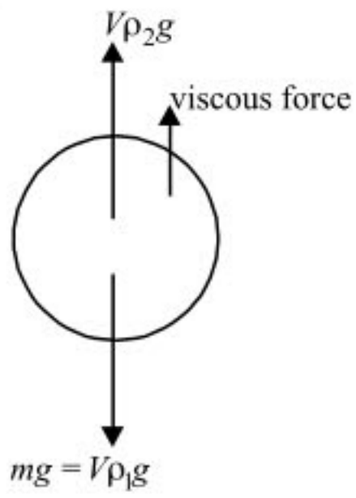
$$\therefore \quad F = Mg - M'g = (M - M')g$$

$$= \left(M - \frac{MD_2}{D_1}\right)g = Mg\left(1 - \frac{D_2}{D_1}\right)$$

5. (c) : Apparent weight = True weight – upward thrust

$$= W - \left(\frac{W}{\rho}\right)\rho_1 = W\left(1 - \frac{\rho_1}{\rho}\right)$$

6. (b) : The forces acting on the solid ball when it is falling through a liquid are mg downwards, up thrust upwards and the viscous force also acting upwards. The viscous force rapidly increases with velocity, attaining a maximum when the ball reaches the terminal velocity.



Then the acceleration is zero.

$mg - V\rho_2 g - kv^2 = ma$

where V is volume, v is the terminal velocity.

When the ball is moving with terminal velocity, $a = 0$.

$$\therefore \quad V\rho_1 g - V\rho_2 g - kv^2 = 0$$

$$v = \sqrt{\frac{Vg(\rho_1 - \rho_2)}{k}}$$

7. (a) : Relative density of liquid

$$= \frac{\text{Loss of weight of body in liquid}}{\text{Loss of weight of body in water}}$$

$$= \frac{210-120}{210-180} = \frac{90}{30} = 3$$

Relative density of metal

$$= \frac{\text{Weight of body in air}}{\text{Loss of weight of body in water}}$$

$$= \frac{210}{210-180} = \frac{210}{30} = 7$$

8. (d) : Rise of liquid in a capillary tube,

$h = \frac{2S\cos\theta}{r\rho g}$ or $h \propto \frac{1}{r}$ $\quad \therefore \quad \frac{h_1}{h_2} = \frac{r_2}{r_1} = \frac{2}{1}$

9. (a) : Excess pressure inside a soap bubble, $P = \frac{4S}{r_1}$

Excess pressure inside an air bubble $P' = \frac{2S}{r_2}$

As per question $P = P'$ $\quad \therefore \quad \frac{4S}{r_1} = \frac{2S}{r_2}$

$\frac{r_1}{r_2} = \frac{4}{2} = \frac{2}{1}$

10. (a) : The pressure at depth h below the surface of a liquid of density ρ open to the atmosphere is

$P = P_a + \rho g h$

where P_a is the atmospheric pressure.

Thus, pressure, P at depth h below the surface of a liquid open to the atmosphere is greater than the atmospheric pressure by an amount $\rho g h$.

11. (b) : Let V be volume of a body.

ρ_b and ρ_l be the density of the body and liquid respectively.

When the body is floating in the liquid, then

Weight of the body = Weight of the liquid displaced.

$$V\rho_b g = V_{in}\rho_l g$$

$$\frac{V_{in}}{V} = \frac{\rho_b}{\rho_l} \qquad \ldots(i)$$

$\therefore$ Volume of the body outside the liquid is

$$V_{out} = V - V_{in} = V - V\frac{\rho_b}{\rho_l} \qquad \text{(Using (i))}$$

$$= V\left(1 - \frac{\rho_b}{\rho_l}\right)$$

$$\therefore \quad \frac{\text{Volume of the body outside the liquid}}{\text{Volume of the body}} = \left(1 - \frac{\rho_b}{\rho_l}\right)$$

As this ratio is independent of the effective value of acceleration due to gravity, so the percentage of the volume of the body outside the liquid will remain unchanged.

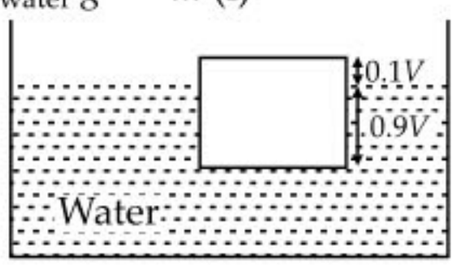
12. (a) : Let V be the volume of an object. When the object is floating in the liquid, then

Weight of the object = Weight of the liquid displaced

$$V\rho_{\text{object}}\, g = V_{\text{inside}}\, \rho_{\text{liquid}}\, g$$

In water,

$V\rho_{\text{object}}\, g = 0.9V\rho_{\text{water}}\, g$ $\quad \ldots$ (i)



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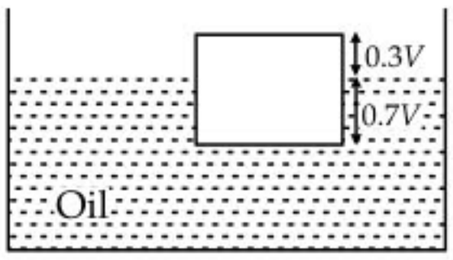
In oil,

$V\rho_{object}\, g = 0.7V\rho_{oil}\, g$ ...(ii)



Divide (i) by (ii), we get

$$1 = \frac{0.9\,\rho_{water}}{0.7\,\rho_{oil}} \quad \text{or} \quad \frac{\rho_{oil}}{\rho_{water}} = \frac{0.9}{0.7} = \frac{9}{7}$$

$$\text{Specific gravity of the oil} = \frac{\rho_{oil}}{\rho_{water}} = \frac{9}{7} = 1.3$$

13. (d) : Here, $h = 2000$ m, $\rho = 10^3$ kgm^{-3}, $g = 10$ ms^{-2}

The pressure outside the submarine is $P = P_a + \rho gh$

where P_a is the atmospheric pressure.

Pressure inside the submarine is P_a.

Hence, net pressure acting on the window is gauge pressure.

Gauge pressure, $P_g = P - P_a = \rho gh$

$= 10^3\ \text{kgm}^{-3} \times 10\ \text{ms}^{-2} \times 2000\ \text{m} = 2 \times 10^7$ Pa

Area of a window is $A = 50\ \text{cm} \times 50\ \text{cm} = 2500 \times 10^{-4}\ \text{m}^2$

Force acting on the window is

$F = P_g A = 2 \times 10^7\ \text{Pa} \times 2500 \times 10^{-4}\ \text{m}^2 = 5 \times 10^6$ N

14. (a) : Rise of a liquid in a capillary tube,

$$h = \frac{2S\cos\theta}{r\rho g}$$

Here, $r = 0.07\ \text{cm} = 0.07 \times 10^{-2}$ m

For water, $S = 0.07$ Nm^{-1}, $\rho = 10^3$ kg m^{-3}

Angle of contact $\theta = 0°$

$$\therefore \quad h = \frac{2 \times (0.07\ \text{Nm}^{-1}) \times 1}{(0.07 \times 10^{-2}\ \text{m})(10^3\ \text{kgm}^{-3})(10\ \text{ms}^{-2})}$$

$$= 2 \times 10^{-2}\ \text{m} = 2\ \text{cm}$$

15. (a) : Total pressure,

P = atmospheric pressure P_0 + pressure due to water column P'

$P = P_0 + P'$

$\therefore \quad P' = P - P_0 = 3 - 1 = 2$ atm

or $\rho gh = 2$ atm

or $h \times 10 \times 10^3 = 2 \times 10^5$

$\therefore \quad h = 20$ m

Velocity of water coming from hole is

$$v = \sqrt{2gh} = \sqrt{2 \times 10 \times 20} = \sqrt{400}\ \text{m s}^{-1}$$

16. (d) : $\text{Density}(\rho) = \dfrac{\text{Mass}\ (M)}{\text{Volume}(V)}$

$\rho \propto \dfrac{1}{V}$ For the same mass.

$$\therefore \quad \frac{\rho_{lead}}{\rho_{iron}} = \frac{V_{iron}}{V_{lead}}$$

As $\rho_{lead} > \rho_{iron}$ (Given)

$$\therefore \quad \frac{V_{iron}}{V_{lead}} > 1 \qquad \text{...(i)}$$

Using law of floatation,

For iron sphere

$W_1 = V_{iron}\, \rho_{water}\, g$ ...(ii)

For lead sphere

$W_2 = V_{lead}\, \rho_{water}\, g$ ...(iii)

Divide (ii) by (iii), we get

$$\frac{W_1}{W_2} = \frac{V_{iron}}{V_{lead}} > 1 \qquad \text{(Using (i))}$$

17. (a)

18. (b) : Figure shows one of the legs of the mosquito landing upon the water surface.

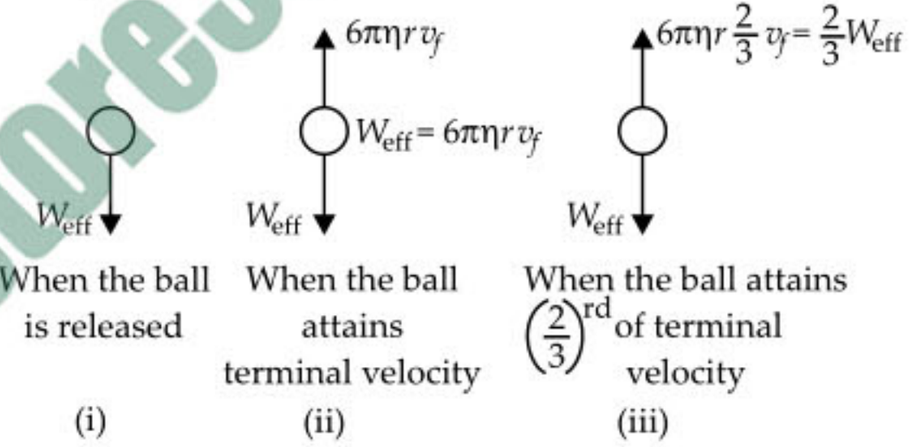
Therefore,

$T\ 2\pi a \times 8 = W$

= weight of the mosquito.

19. (c) : The force exerted by film on wire or thread depends only on the nature of material of the film and not on its surface area. Hence, the radius of circle formed by elastic thread does not change.

20. (a) :



When the ball is released (i) | When the ball attains terminal velocity (ii) | When the ball attains $\left(\frac{2}{3}\right)^{rd}$ of terminal velocity (iii)

When the ball is just released, the net force on ball is W_{eff} (= mg – buoyant force)

The terminal velocity v_f of the ball is attained when net force on the ball is zero.

$\therefore$ Viscous force, $6\pi\eta r v_f = W_{eff}$

When the ball acquires $\left(\frac{2}{3}\right)^{rd}$ of its maximum velocity v_f, the viscous force is $= \frac{2}{3} W_{eff}$

Hence, net force is $W_{eff} - \frac{2}{3} W_{eff} = \frac{1}{3} W_{eff}$

$\therefore$ Required acceleration is $= \frac{a}{3}$

21. (d) : $F = \eta A \dfrac{dv}{dx}$

$$\text{or } dx = \eta \frac{A\,dv}{F} = \frac{0.001 \times (0.1)^2 \times 0.1}{0.002} = 0.0005\ \text{m}$$

22. (d) : According to Archimedes' principle

Weight of the body = Weight of the liquid displaced

Let V be volume of the block.

In water

$$V\rho_{block} g = \left(\frac{4}{5}V\right)\rho_{water} g$$

$$\rho_{block} = \frac{4}{5}\rho_{water} \qquad \text{...(i)}$$

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In liquid,

$V\rho_{block}g = V\rho_{liquid}g$

$\rho_{block} = \rho_{liquid}$ ...(ii)

From (i) and (ii), we get

$$\rho_{liquid} = \frac{4}{5}\rho_{water} = \frac{4}{5}\times 10^3 \text{ kg m}^{-3} = 800 \text{ kg m}^{-3}$$

23. (a) : Rise of liquid in a capillary tube,

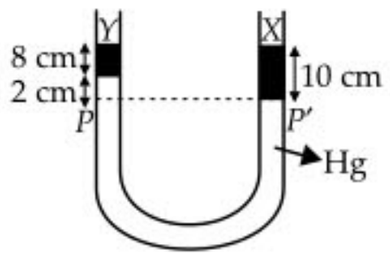
$$h = \frac{2S\cos\theta}{r\rho g}$$

$$h \propto \frac{1}{g}$$

$$\therefore \quad \frac{h_{moon}}{h_{earth}} = \frac{g_{earth}}{g_{moon}} = \frac{6g_{moon}}{g_{moon}} = 6$$

$h_{moon} = 6h_{earth}$

24. (a) : As shown in adjacent figure, in the two arms of a tube pressure remains same on surface PP'. Hence,



$8 \times \rho_Y \times g + 2 \times \rho_{Hg} \times g = 10 \times \rho_X \times g$

$\therefore \quad 8\rho_Y + 2 \times 13.6 = 10 \times 3.36$

or $\quad \rho_Y = \dfrac{33.6 - 27.2}{8} = 0.8 \text{ g cm}^{-3}$

25. (d)

26. (a) : According to Poiseuille formula,

Rate of flow, $V = \dfrac{\pi P r^4}{8\eta l}$

where the symbols have their usual meanings.

$\therefore \quad P = \dfrac{V 8\eta l}{\pi r^4}$

Here, $V = 2 \times 10^{-3} \text{ m}^3 \text{ s}^{-1}$

$r = \dfrac{8}{2}\text{cm} = 4 \text{ cm} = 4 \times 10^{-2} \text{ m}$

$l = 3140$ m, $\eta = 10^{-3}$ N s m^{-2}

Substituting the given values, we get

$$P = \frac{(2\times 10^{-3} \text{ m}^3 \text{ s}^{-1})(8)(10^{-3} \text{N s m}^{-2})(3140 \text{ m})}{(3.14)(4\times 10^{-2} \text{m})^4}$$

$= 6.25 \times 10^3 \text{ N m}^{-2}$

27. (d) : When the coin falls, the block moves upwards, hence l decreases; h will also decrease because when the coin is in the water it will displace equal volume of water, whereas when it is on the block an equal weight of water is displaced.

28. (c) : Pressure difference between lungs and atmosphere (760 – 750) mm of Hg = 10 mm of Hg = 1 cm of Hg.
If one can draw from a depth of l cm of water, then,
pressure difference $= 1 \times 13.6 \times 980 = l \times 1 \times 980$
or $\quad l = 13.6$ cm of water.

29. (d) : Let R be radius of large drop and r be radius of each small drop.

$$\therefore \quad \frac{4}{3}\pi R^3 = 1000 \times \frac{4}{3}\pi r^3$$

$$R = 10r$$

Surface energy of small drop, $E_1 = S \times 4\pi r^2$

Surface energy of large drop, $E_2 = S \times 4\pi(10r)^2$

$$\therefore \quad \frac{E_1}{E_2} = \frac{1}{100}$$

30. (d) : Strain rate $= \dfrac{v}{l} = \dfrac{10 \text{ m s}^{-1}}{20 \text{ m}} = 0.5 \text{ s}^{-1}$

Coefficient of viscosity, $\eta = \dfrac{\text{Shearing stress}}{\text{Strain rate}}$

$\therefore$ Shearing stress $= \eta \times$ Strain rate

$= 10^{-3}$ N s m$^{-2} \times 0.5$ s^{-1}

$= 0.5 \times 10^{-3}$ N m^{-2}

31. (d) : Given : $d = 0.28$ mm $= 0.28 \times 10^{-3}$ m

$r = 0.14 \times 10^{-3}$ m

Surface tension, $S = 0.07$ N m^{-1}

Atmospheric pressure $= 10^5$ N m^{-2}

$$S = \frac{rh\rho g}{2} = 0.07$$

$$0.07 = \frac{P \times 0.14 \times 10^{-3}}{2} \qquad (\because P = h\rho g)$$

$P = 1 \times 10^3$ N m^{-2}

Total pressure $= P +$ Atmospheric pressure

$= 10^3$ N m$^{-2} + 10^5$ N m^{-2}

$= 10^3(1 + 100)$ N m^{-2}

$= 101 \times 10^3$ N m^{-2}

32. (a) : Velocity of efflux, $v = \sqrt{2gh}$

Volume of liquid flowing out per second

$= v \times A = \sqrt{2gh} \times A$

$= \sqrt{2 \times 10 \times 5} \times (10 \times 10^{-4}) = 10^{-2} \text{ m}^3 \text{ s}^{-1}$

33. (d) : Let V be the volume of wooden ball. The mass of ball is $m = V\rho$.

Upward acceleration,

$$a = \frac{\text{Upward thrust} - \text{Weight of ball}}{\text{Mass of ball}}$$

$$= \frac{V\rho_0 g - V\rho g}{V\rho} = \frac{(\rho_0 - \rho)g}{\rho} \qquad \text{...(i)}$$

If v is the velocity of ball on reaching the surface after being released at depth h is

$$v = \sqrt{2as} = \left[2\left(\frac{\rho_0 - \rho)}{\rho}\right)gh\right]^{1/2} \qquad \text{(Using(i))...(ii)}$$

If h' is the vertical distance reached by ball above the surface of water, then

$$h' = \frac{v^2}{2g} = \frac{2(\rho_0 - \rho)}{\rho}gh \times \frac{1}{2g} \qquad \text{(Using (i))}$$

$$= \left(\frac{\rho_0 - \rho}{\rho}\right)h = \left(\frac{\rho_0}{\rho} - 1\right)h$$

34. (d) : Let the velocity of liquid from hole in tank A is v_1 and velocity of liquid from hole in tank B is v_2.
From equation of continuity,

$A_1 v_1 = A_2 v_2$

$Av_1 = 2A v_2$

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or $\frac{v_2}{v_1} = \frac{1}{2}$ ...(i)

Volume of liquid coming out per second from hole in tank $A = A_1 v_1$

Mass of liquid coming out per second from hole in tank $A = A_1 v_1 \rho_1$

Similarly,

Volume of liquid coming out per second from hole in tank $B = A_2 v_2$

Mass of liquid coming out per second from hole in tank $B = A_2 v_2 \rho_2$

Liquid mass flux, ϕ_m = Mass of liquid flowing per second per unit area

$\therefore \quad \phi_{m_A} = \frac{A_1 v_1 \rho_1}{A_1} = v_1 \rho_1$ and $\phi_{m_B} = \frac{A_2 v_2 \rho_2}{A_2} = v_2 \rho_2$

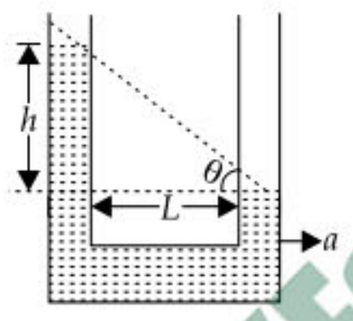
As per question, $\phi_{m_A} = \phi_{m_B}$

$\therefore \quad v_1 \rho_1 = v_2 \rho_2$ or $\frac{\rho_1}{\rho_2} = \frac{v_2}{v_1} = \frac{1}{2}$ (Using(i))

35. (d) : Let P_1 and P_2 be the pressures at the bottom of the left end and right end of the tube respectively. Then

$F = (P_1 - P_2)A = \rho g h A$

where A is the area of cross-section of the tube.



The mass of the liquid in the horizontal portion is

$m = \rho L A$

As $F = ma$

$\therefore \quad \rho g h A = \rho L A a$ or $h = \frac{aL}{g}$

36. (a) : The weight of the aeroplane is balanced by the upward force due to pressure difference.

$\therefore \quad \Delta P A = mg$ or $\Delta P = \frac{mg}{A}$

Substituting the given values, we get

$$\Delta P = \frac{3 \times 10^4 \text{ kg} \times 10 \text{ m s}^{-2}}{120 \text{ m}^2} = \frac{1}{4} \times 10^4 \text{ N m}^{-2}$$
$$= 2.5 \times 10^3 \text{ Pa} = 2.5 \text{ kPa}$$

37. (a) : Weight of block of steel in air = $(5 \times 5 \times 5) \times 7 \times g$

Weight of water displaced by block of steel when immersed in water = $(5 \times 5 \times 5) \times 1 \times g$

$\therefore$ Apparent weight

$= 5 \times 5 \times 5 \times 7 \times g - 5 \times 5 \times 5 \times 1 \times g = 5 \times 5 \times 5 \times 6 \times g$

38. (c) : Velocity of efflux, $v = \sqrt{2gd}$

Time taken by the water to reach the gound from a vertical height h is

$t = \sqrt{\frac{2h}{g}}$ $\left(\because h = 0 + \frac{1}{2} g t^2\right)$

Horizontal range, $R = vt$

$R = \sqrt{2gd}\sqrt{\frac{2h}{g}} = 2\sqrt{hd}$ or $d = \frac{R^2}{4h}$

39. (a) : For equilibrium,

Weight = Force of buoyancy

or $mg = V_{in} \sigma g$ or $\rho V = V_{in} \sigma$

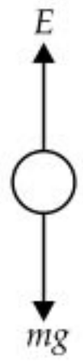
$V_{in} = \frac{\rho V}{\sigma}$ $\quad \therefore \quad V_{out} = V - V_{in} = V\left(1 - \frac{\rho}{\sigma}\right)$

$\text{Fraction} = \frac{V_{out}}{V} = 1 - \frac{\rho}{\sigma} = \left(1 - \frac{0.92}{1.03}\right) = 0.106$

40. (d) : Pressure = $h\rho g$; is independent of area and mass of the liquid in vessel but depends upon height h and density ρ of the liquid.

41. (d) : Since the drop is held stationary,

$\therefore$ Force on the drop due to electric field = Weight of the drop



$qE = mg$ or $ne\frac{V}{d} = mg$

$\therefore \quad n \times 1.6 \times 10^{-19} \times \frac{1200}{6 \times 10^{-3}} = 3.2 \times 10^{-14} \times 10$

or $n = \frac{3.2 \times 10^{-13} \times 6 \times 10^{-3}}{1.6 \times 10^{-19} \times 1200} = 10$

42. (b)

43. (c) : $h = \frac{2S\cos\theta}{r\rho g}$

$hr = \frac{2S\cos\theta}{\rho g} = \text{constant}$ or $h_1 r_1 = h_2 r_2$ or $h_2 = \frac{h_1 r_1}{r_2}$

Substituting the values, we get

$h_2 = \frac{(2.0 \text{ cm})(r_1)}{\left(\frac{r_1}{3}\right)} = 6.0 \text{ cm}$

44. (b) : If A_0 is the area of orifice at the bottom below the free surface and A that of vessel, time t taken to empty the tank,

$t = \frac{A}{A_0}\sqrt{\frac{2H}{g}}$

$\therefore \quad \frac{t_1}{t_2} = \sqrt{\frac{H_1}{H_2}} = \sqrt{\frac{H_1}{H_1/2}}$

$\therefore \quad t_2 = \frac{t_1}{\sqrt{2}} = \frac{10 \text{ min}}{\sqrt{2}} \approx 7 \text{ min}$

45. (b) : Here, diameter of the hose, $D = 2.0$ cm,

Speed of water in the hose, $V = 90.0 \text{ cm s}^{-1}$,

Diameter of each hole, $d = 0.125$ cm

number holes, $n = 24$

Let v be the velocity of water flowing out of each hole. Volume of the water crossing hose per second is equal to the volume of the water leaving out per second through holes. So

$\frac{\pi D^2}{4} \times V = n\frac{\pi d^2}{4} \times v$

or $v = \frac{D^2 V}{nd^2} = \frac{(2 \text{ cm})^2 \times 90.0 \text{ cm s}^{-1}}{24 \times (0.125 \text{ cm})^2} = 960 \text{ cm s}^{-1}$

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Thermal Properties of Matter

Heat

Heat is the form of energy that flows between a body and its surrounding medium by virtue of temperature difference between them.

The SI unit of heat is joule.

The practical unit of heat is calorie.

1 calorie is the amount of heat required to raise the temperature of 1 g of water from 14.5°C to 15.5°C.

Joule found that when mechanical work (W) is converted into heat (Q), the ratio of W and Q is always constant, represented by J,

$$i.e.\ \frac{W}{Q} = J \quad \text{or} \quad W = JQ$$

where J is Joule's mechanical equivalent of heat. J is not a physical quantity but a conversion factor involved when work is converted into heat or vice-versa. The value of J = 4.186 joule/calorie *i.e.* 1 calorie = 4.186 joule.

Temperature

Temperature is basically a measure of degree of hotness or coldness of a body.

Different temperature scales

S. No.	Name of the scale	Symbol for each degree	Lower fixed point (LFP)	Upper fixed point (UFP)	Number of divisions on the scale
1.	Celsius	°C	0°C	100°C	100
2.	Fahrenheit	°F	32°F	212°F	180
3.	Reaumur	°R	0°R	80°R	80
4.	Rankine	°Ra	460 Ra	672 Ra	212
5.	Kelvin	K	273.15K	373.15K	100

Relationship between Different Temperature Scales

$$\frac{T_C - 0}{100} = \frac{T_F - 32}{180} = \frac{T_R - 0}{80} = \frac{T_{Ra} - 460}{212} = \frac{T_K - 273.15}{100}$$

Temperature on one scale can be converted into another scale by using the following identity :

$$\frac{\text{Reading on any scale} - \text{lower fixed point (LFP)}}{\text{Upper fixed point (UFP)} - \text{lower fixed point (LFP)}} = \text{constant for all scales}$$

Thermometer

Thermometer is an instrument used to measure temperature of a body.

Type of Thermometers

- Liquid thermometers
- Gas thermometers
- Resistance thermometers
- Thermoelectric thermometers
- Pyrometers
- Vapour pressure thermometers

Thermal expansion

All solids are found to expand on heating. Thermal expansion of solids is of three types:

- Linear expansion
- Area expansion
- Volume expansion

Coefficient of linear expansion of a solid,

$$\alpha = \frac{\text{increase in length}}{\text{original length} \times \text{rise in temperature}}$$

Coefficient of area expansion of a solid,

$$\beta = \frac{\text{increase in area}}{\text{original area} \times \text{rise in temperature}}$$

Coefficient of volume expansion of a solid,

$$\gamma = \frac{\text{increase in volume}}{\text{original volume} \times \text{rise in temperature}}$$

Relation between α, β and γ

$$\alpha = \frac{\beta}{2} = \frac{\gamma}{3}.$$

The units of α, β and γ are the same.

i.e. $°C^{-1}$ or K^{-1}.

When temperature increases (during summer), the length of the pendulum increases due to which the time period increases and the clock loses time. On the other hand, when temperature decreases (during winter season), the length decreases and the time period decreases. The clock gains time.

The loss or gain of time $\Delta t = \frac{1}{2}\alpha(\Delta T)t$.

where α is the coefficient of linear expansion.

ΔT = change in temperature and t = time interval in which we have to find loss or gain of time. If it is per day,

$t = 24 \times 60 \times 60 = 86400$ s

There are two types of coefficients of expansion in case of liquids.

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- Coefficient of real expansion
- Coefficient apparent expansion

Coefficient of real expansion of a liquid,

$$\gamma_r = \frac{\text{real increase in volume}}{\text{original volume} \times \text{rise in temperature}}$$

Coefficient of apparent expansion of a liquid

$$\gamma_a = \frac{\text{apparent increase in volume}}{\text{original volume} \times \text{rise in temperature}}$$

$\gamma_r = \gamma_a + \gamma_g$, where γ_g is coefficient of volume expansion of the container.

Anomalous expansion of water

Generally matter expands on heating and contracts on cooling. In case of water, it expands on heating if its temperature is greater than 4°C. In the range 0°C to 4°C, water contracts on heating and expands on cooling, (*i.e.*, its coefficient of volume expansion in this range is negative). This behaviour of water in the range from 0°C to 4°C is called anomalous expansion.

Water has a maximum density a 4°C.

Specific heat or specific heat capacity

It is defined as the amount of heat required to raise the temperature of unit mass of the substance through 1°C.

The specific heat of a substance is given by

$$s = \frac{1}{m}\frac{\Delta Q}{\Delta T}$$

where m is the mass of the substance and ΔQ is the heat required to change its temperature by ΔT.

The SI unit of specific heat is J kg^{-1} K^{-1}.

The practical unit of specific heat is cal g^{-1} $°C^{-1}$.

Specific heat depends on the nature of the substance and its temperature.

Specific heat for hydrogen is maximum (= 3.5 cal g^{-1} $°C^{-1}$) and for water, it is 1 cal g^{-1} $°C^{-1}$. For all other substances, the specific heat is less than 1 cal g^{-1} $°C^{-1}$.

Molar specific heat or Molar heat capacity

It is defined as amount of heat required to raise the temperature of one mole of substance through 1°C.

The molar specific heat of a substance is given by

$$C = \frac{1\Delta Q}{\mu \Delta T}$$

where μ is the number of the moles.

The SI unit of molar specific heat is J mol^{-1} K^{-1}.

Molar specific heat also depends on the nature of the substance and its temperature.

Gas has two types of molar specific heats

- Molar specific heat at constant volume (C_V)
- Molar specific heat at constant pressure (C_P)

Change of state

Matter normally exists in three states, *i.e.*, solid, liquid and gas. A transition from one of these states to another is known as change of state.

Melting : The change of state from solid to liquid is known as melting.

Fusion : The change of state from liquid to solid is known as fusion.

Melting point : The temperature at which the solid and liquid states of the substance are in thermal equilibrium with each other is called its melting point. It is the characteristic of the substance. It also depends on pressure. The melting point of a substance at standard atmospheric pressure is called its normal melting point.

Vaporisation : The change of state from liquid to vapour is known as vaporisation.

Boiling point : The temperature at which the liquid and the vapour states of the substance co-exist is called its boiling point. It is the characteristic of the substance. It also depends on pressure. The boiling point of a substance at standard atmospheric pressure is called its normal melting point.

The boiling point of a substance increases with increase in pressure. Due to this fact, the cooking is easier in the pressure cooker. The boiling point of a substance decreases with decrease in pressure. Due to this fact, the cooking is difficult on hill station.

Sublimation : The change from solid state to vapour state without passing through the liquid state is known as sublimation.

Latent heat

It is defined as the amount of heat required to change the state of a unit mass of the substance at a constant temperature.

The latent heat of a substance is given by

$$L = \frac{Q}{m}$$

where m is the mass of a substance.

The SI unit of latent heat is J kg^{-1} while practical unit is cal g^{-1}.

Latent heat of fusion : It is the amount of heat required to change unit mass of the solid into liquid at constant temperature *e.g.* latent heat of fusion of ice = 80 cal g^{-1}.

Latent heat of vaporisation : It is the amount of heat required to change unit mass of the liquid into vapour at constant temperature. e.g. latent heat of vaporisation of water = 540 cal g^{-1}.

Principle of calorimetry

When two bodies at different temperatures are placed in contact with each other then heat will pass from the body at higher temperature to the body at lower temperature until both reach a common temperature. *i.e.* heat lost by one body = heat gained by the other.

Principle of calorimetry obeys law of conservation of energy

Conduction

If a metal spoon is put in a cup of hot tea, after some time its other end also becomes warm. Heat is transferred from

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one end of the spoon to the other end due to molecular vibrations within the spoon. This process is called thermal conduction. In this process there is no movement of mass. In the beginning of conduction process of a part of heat is absorbed at every cross-section and the remaining part is transported to the next section. But after time a steady-state is reached and the temperature of all the parts of the conductor becomes constant.

Convection

Convection is that method of heat transfer in which the heat is carried from one place to another by actual movement of heated matter. This process can occur only in fluids. If the heated matter is forced to move by some agent (like a fan) then the process is known as forced convection. If the matter flows on its own due to difference of pressure it is known as natural or free convection. For example air coolers and hot air blowers are examples of forced convection, whereas Monsoon is an example of natural convection.

Radiation

Radiation is that method of heat transfer which does not require any material medium. In this process heat energy is transferred in the form of electro-magnetic waves. The properties of radiation are similar to those of light.

- It travels with the velocity of light (3×10^8 m s^{-1} in vacuum)
- It shows all the properties of light, *i.e.* reflection, interference, polarization etc.
- It obeys inverse square law.

Wien's displacement law

The wavelength corresponding to highest intensity λ_m is inversely proportional to the absolute temperature. Thus

$$\lambda_m = \frac{b}{T}$$

where b ($= 2.89 \times 10^{-3}$ meter kelvin) is known as the Wien's constant.

Wien's the temperature of a black body is increased the contribution of low wavelength radiation increases. This explains why a body on heating first appears red, then orange, then white and finally blue. This law also helps us in determining the temperatures of the stars.

Stefan's law

The energy emitted per second per unit area of a black body is proportional to the fourth power of corresponding absolute temperature. Thus, the energy of thermal radiation emitted per unit time by a black body of surface area A is given by

$$Q = \sigma A T^4$$

Where $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4} is a universal constant, known as Stefan's constant.

For a non-black body

$Q = e\,\sigma A T^4$, where e is the emissivity of that body

For a body kept in surroundings of temperature T_0 the net lose of thermal energy per unit time

$\Delta Q = e\sigma A(T^4 - T_0^4)$ as the body absorbs $e\sigma A T_0^4$ energy during the same period

Newton's law of cooling

It states that the rate of cooling of a body is proportional to the excess temperature of the body over the surroundings

$$\frac{dQ}{dt} = -K(T - T_0)$$

where T_0 is the temperature of the surrounding medium and T is the temperature of the body.

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EXAM DRILL

1. A thin brass sheet at 10°C, and a thin steel sheet at 20°C have the same surface area. The common temperature at which both would have the same area is (Coefficient of linear expansion for brass and steel are $19 \times 10^{-6}°C^{-1}$ and $11 \times 10^{-6}°C^{-1}$ respectively)
(a) –3.75°C (b) –2.75°C
(c) +2.75°C (d) +3.75°C

2. An object cools from 75°C to 65°C in 2 minutes in a room at 30°C. The time taken to cool from 55°C to 45°C in the same room in minutes will be
(a) 4 (b) 5
(c) 6 (d) 7

3. The net rate at which heat is lost by a body due to radiation does not depend upon
(a) temperature of the body
(b) temperature of the surroundings
(c) material of the body
(d) nature of its surface

4. A body takes 10 min to cool from 60°C to 50°C. If the temperature of surroundings is 25 °C, then temperature of body after next 10 min will be
(a) 45°C (b) 42.85°C
(c) 30°C (d) 32.50°C

5. A slab of stone of area 0.36 m^2 and thickness 0.1 m is exposed on the lower surface to steam at 100°C. A block of ice at 0°C rests on the upper surface of the slab. In one hour 4.8 kg of ice is melted. The thermal conductivity of slab is
(Given latent heat of fusion of ice = 3.36×10^5 J kg^{-1})
(a) 1.24 J/m/s/°C (b) 1.29 J/m/s/°C
(c) 2.05 J/m/s/°C (d) 1.02 J/m/s/°C

6. Hot food cools from 94°C to 86°C in 2 minutes when the the room temperature is 20°C. How long would the the food take to cool from 71°C to 69°C?
(a) 12 sec (b) 25 sec
(c) 16 sec (d) 42 sec

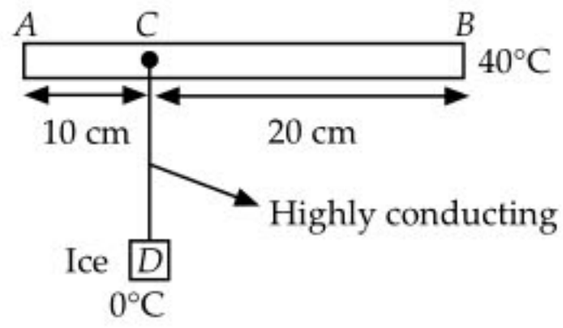
7. A one litre flask contains certain quantity of mercury. If the volume of air inside the flask remains the same at all temperatures then the volume of mercury in the flask is
(volume expansion coefficient of mercury is 20 times that of flask)
(a) 100 cc (b) 50 cc
(c) 200 cc (d) 150 cc

8. The rate of dissipation of heat by a black body at temperature T is Q. What will be the rate of dissipation of heat by another body at temperature $2T$ and emissivity 0.25?
(a) $16Q$ (b) $4Q$
(c) $8Q$ (d) $4.5Q$

9. A hot body is allowed to cool. The surrounding temperature is constant at 30°C. The body takes time t_1 to cool from 90°C to 89°C and time t_2 to cool from 60°C to 59.5°C. Then,
(a) $t_2 = 2t_1$ (b) $t_2 = \frac{t_1}{2}$ (c) $t_2 = 4t_1$ (d) $t_2 = t_1$

10. The temperature of a perfect black body is 727°C and its area is 0.1 m^2. If Stefan's constant is 5.67×10^{-8} W m^{-2} K^{-4}, then heat radiated by it in 0.3 minutes is
(a) 1701 J (b) 17010 J
(c) 102060 J (d) 102.06 J

11. In the figure shown, AB is a rod of length 30 cm and area of cross-section 1.0 cm^2 and thermal conductivity 336 SI units. The ends A and B are maintained at temperatures 20°C and 40°C respectively. A point C of this rod is connected to a box D, containing ice at 0°C, through a highly conducting wire of negligible heat capacity. The rate at which ice melts in the box is
[Assume latent heat of fusion for ice, $L_f = 80$ cal g^{-1}]

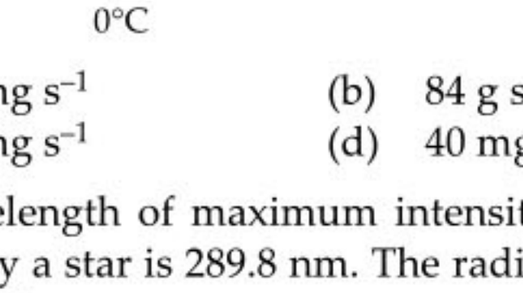


(a) 84 mg s^{-1} (b) 84 g s^{-1}
(c) 20 mg s^{-1} (d) 40 mg s^{-1}

12. The wavelength of maximum intensity of radiation emitted by a star is 289.8 nm. The radiation intensity of the star is
(Stefan's constant = 5367×10^{-8} W m^{-2} K^{-4}, Wien's constant b = 2898 μm = K)
(a) 5.67×10^8 W m^{-2} (b) 5.67×10^{12} W m^{-2}
(c) 10.67×10^7 W m^{-2} (d) 10.67×10^{14} W m^{-2}

13. 1 g of ice is mixed with 1 g of steam. After thermal equilibrium is reached, the temperature of mixture is
(a) 100°C (b) 55°C (c) 75°C (d) 0°C

14. Three rods of same dimensions have thermal conductivities $3K$, $2K$ and K respectively. They are arranged as shown below



What will be the temperature T of the junction?
(a) $\frac{200}{3}$°C (b) $\frac{100}{3}$°C (c) 75°C (d) $\frac{50}{3}$°C

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15. A body cools 70°C to 50°C in minutes. Temperature of surroundings is 20°C. Its temperature after next 10 minutes is
(a) 25°C (b) 30°C
(c) 35°C (d) 45°C

16. The temperature of equal masses of three different liquids A, B and C are 12°C, 19°C and 28°C respectively. The temperature when A and B are mixed is 16°C and when B and C are mixed is 23°C. The temperature when A and C are mixed is
(a) 182°C (b) 22°C
(c) 20.2°C (d) 24.2°C

17. A black body has maximum wavelength λ_m at 2000 K. Its corresponding wavelength at 3000 K will
(a) $\frac{3}{2}\lambda_m$ (b) $\frac{2}{3}\lambda_m$ (c) $\frac{16}{81}\lambda_m$ (d) $\frac{81}{16}\lambda_m$

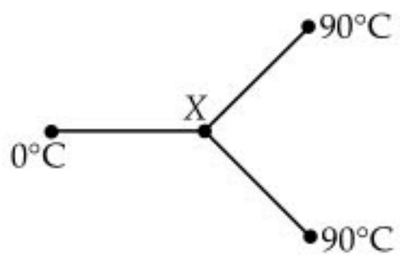
18. A body cools down from 60°C to 55°C in 30 s. Using Newton's law of cooling, calculate the approximate time taken by same body to cool down from 55°C to 50°C. Assume that the temperature of surroundings is 45°C.
(a) 40 s (b) 55 s
(c) 50 s (d) 60 s

19. The specific heat capacity of a metal at low temperature (T) is given as

$$C(\text{kJ K}^{-1}\text{ kg}^{-1}) = 32\left(\frac{T}{400}\right)^3$$

A 100 g vessel of this metal is to be cooled from 20 K to 4 K by a special refrigerator operating at room temperature (27°C). The amount of work required to cool the vessel is
(a) equal to 0.002 kJ
(b) greater than 0.148 kJ
(c) between 0.148 kJ and 0.028 kJ
(d) less than 0.028 kJ

20. Three metal rods of the same material and identical in all respects are joined as shown in the figure. The temperatures at the ends are maintained as indicated. Assuming no loss of heat from the curved surfaces of the rods, the temperature at the junction X would be



(a) 45°C (b) 60°C
(c) 30°C (d) 20°C

21. A blacksmith fixes iron ring on the rim of the wooden wheel of a bullock cart. The diameter of the rim and the iron ring are 5.24 m and 5.23 m respectively at 27°C. To what temperature should be ring be heated so as to fit the rim of the wheel?
(Coefficient of linear expansion of iron = $1.2 \times 10^{-5}°C^{-1}$)
(a) 166°C (b) 176°C
(c) 186°C (d) 196°C

22. Thermal stress does not depend upon
(a) length of the rod
(b) coefficient of linear expansion
(c) Young's modulus
(d) nature of the material

23. Two bars of same length and same cross-sectional area but of different thermal conductivities K_1 and K_2 are joined end to end as shown in the figure. One end of the compound bar is at temperature T_1 and the opposite end at temperature T_2 (where $T_1 > T_2$). The temperature of the junction is

(a) $\frac{K_1T_1 + K_2T_2}{K_1 + K_2}$ (b) $\frac{K_1T_2 + K_2T_1}{K_1 + K_2}$
(c) $\frac{K_1(T_1 + T_2)}{K_2}$ (d) $\frac{K_2(T_1 + T_2)}{K_1}$

24. 10 g of ice at 0°C is mixed with 100 g of water at 50°C in a calorimeter. The final temperature of the mixture is [Specific heat of water = 1 cal g^{-1} $°C^{-1}$, latent heat of fusion of ice = 80 cal g^{-1}]
(a) 31.2°C (b) 32.8°C
(c) 36.7°C (d) 38.2°C

25. At 50°C, a brass rod has a length 50 cm and a diameter 2.0 mm. It is joined to a steel rod of the same length and diameter at the same temperature. The change in the length of the composite rod when it is heated to 250°C is
[Coefficient of linear expansion of brass = $2.0 \times 10^{-5}°C^{-1}$, coefficient of linear expansion of steel = $1.2 \times 10^{-5}°C^{-1}$]
(a) 0.28 cm (b) 0.30 cm
(c) 0.32 cm (d) 0.34 cm

26. If T denotes the temperature of the gas, the volume thermal expansion coefficient of an ideal gas at constant pressure is
(a) $\frac{1}{T}$ (b) T (c) T^2 (d) $\frac{1}{T^2}$

27. The net rate at which heat is lost by a body due to radiation does not depend upon
(a) temperature of the body
(b) temperature of the surroundings
(c) material of the body
(d) nature of its surface

28. The radius of a metal sphere at room temperature T is R, and the coefficient of linear expansion of the metal is α. The sphere is heated a little by a temperature ΔT so that its new temperature is $T + \Delta T$. The increase in the volume of the sphere is approximately
(a) $2\pi R^3\alpha\Delta T$ (b) $\pi R^3\alpha\Delta T$
(c) $\frac{4\pi R^3\alpha\Delta T}{3}$ (d) $4\pi R^3\alpha\Delta T$

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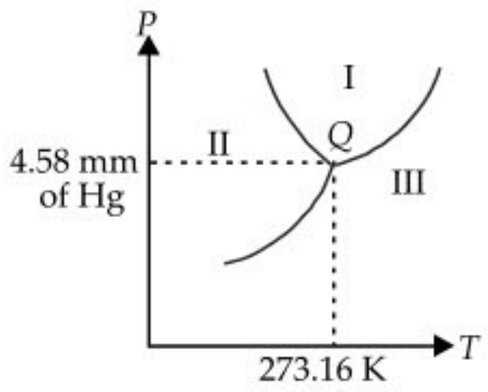
29. In which of the following process convection does not take place primarily?
(a) Sea and land breeze
(b) Trade wind
(c) Boiling of water
(d) Warming of glass of bulb due to filament

30. Which of the following liquids show anomalous expansion?
(a) Ethanol (b) Water
(c) Glycerin (d) Benzene

31. The coefficient of volume expansion of liquid is γ. The fractional change in its density for ΔT rise in temperature is
(a) $\gamma\Delta T$ (b) $\frac{\Delta T}{\gamma}$ (c) $1+\gamma\Delta T$ (d) $1-\gamma\Delta T$

32. In the phase diagram shown, the point Q corresponds to the triple point of water. The regions I, II and III respectively correspond to phases



(a) liquid, solid, vapour
(b) solid, liquid, vapour
(c) liquid, vapour, solid
(d) solid, vapour, liquid

33. A brass wire 1.8 m long at 27°C is held taut with negligible tension between two rigid supports. Diameter of the wire is 2 mm, its coefficient of linear expansion, $\alpha_{Brass} = 2 \times 10^{-5}°C^{-1}$ and its Young's modulus, $Y_{Brass} = 9 \times 10^{10}$ N m^{-2}. If the wire is cooled to a temperature – 39°C, tension developed in the wire is
(a) 2.7×10^2 N (b) 3.7×10^2 N
(c) 4.7×10^2 N (d) 5.7×10^2 N

34. A body cools from 80°C to 50°C in 5 minutes. If the surroundings temperature is 20°C, then the time it takes to cool from 60°C to 30°C is
(a) 240 s (b) 300 s
(c) 540 s (d) 600 s

35. The density of water at 4°C is 1000 kg m^{-3} and at 100°C it is 958.4 kg m^{-3}. The coefficient of volume expansion of water is
(a) 4.5×10^{-3} °C^{-1} (b) 5.4×10^{-5} °C^{-1}
(c) 4.5×10^{-4} °C^{-1} (d) 5.4×10^{-6} °C^{-1}

36. The latent heat of vaporisation of a substance is always
(a) greater than its latent heat of fusion.
(b) greater than its latent heat of sublimation.
(c) equal to its latent heat of sublimation.
(d) less than its latent heat of fusion.

37. Which of the following qualities are best suited for a cooking utensil?
(a) Low specific heat and high thermal conductivity.
(b) Low specific heat and low thermal conductivity.
(c) High specific heat and high thermal conductivity.
(d) High specific heat and low thermal conductivity.

38. In a pressure cooker, cooking is faster because the increase of pressure
(a) increases specific heat
(b) decreases specific heat
(c) increases the boiling point
(d) decreases the boiling point

39. A sphere, a cube and a thin circular plate, all of same material and same mass are initially heated to same high temperature.
(a) Plate will cool fastest and cube the slowest
(b) Sphere will cool fastest and cube the slowest.
(c) Plate will cool fastest and sphere the slowest.
(d) Cube will cool fastest and plate the slowest.

40. A glass full of hot milk is poured on the table. It begins to cool gradually. Which of the following is incorrect?
(a) The rate of cooling is constant till milk attains the temperature of the surroundings.
(b) The temperature of milk falls off exponentially with time.
(c) While cooling, there is a flow of heat from milk to the surroundings as well as from surroundings to the milk but the net flow of heat is from milk to the surroundings and that is why it cools.
(d) All three phenomenon, conduction, convection and radiation are responsible for the loss of heat from milk to the surroundings.

41. A cubical thermocole ice box of side 20 cm has a thickness 5 cm. If 5 kg of ice is put in the box, the amount of ice remaining after 10 hours is

(The outside temperature is 50°C coefficient of thermal conductivity of thermocole = 0.01 J s^{-1} m^{-1} °C^{-1}, latent heat of fusion of ice = 335×10^3 J kg^{-1})
(a) 3.7 kg (b) 3.9 kg
(c) 4.7 kg (d) 4.9 kg

42. As the temperature is increased, the time period of a pendulum
(a) increases as its effective length increases even though its centre of mass still remains at the centre of the bob.
(b) decreases as its effective length increases even though its centre of mass still remains at the centre of the bob.
(c) increases as its effective length increases due to shifting of centre of mass below the centre of the bob.
(d) decreases as its effective length remains same but the centre of mass shifts above the centre of the bob.

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43. Two spheres A and B are made of the same material and have the same radius. Sphere A is is hollow and sphere B is solid. Both the spheres are heated to the same temperature. Which of the following is correct?

(a) A expands more than B.
(b) A expands less than B.
(c) Both the spheres expand equally.
(d) Data is insufficient.

44. Two absolute scales A and B have triple points of water defined to be 200 A and 400 B. The relationship between T_A and T_B is
(Triple point of water = 273.16 K)

(a) $T_A = \frac{1}{2}T_B$ (b) $T_A = 2T_B$
(c) $T_A = \frac{1}{4}T_B$ (d) $T_A = 4T_B$

45. Rays from the sun are focused by a lens of diameter 5 cm on to a block of ice and 10 g of ice is melted in 20 min. Therefore the heat from the sun reaching the earth per min per square centimetre is
(Latent heat $L = 80$ cal g^{-1})

(a) 2.04 cal (b) 0.51 cal
(c) 4.08 cal (d) 3.02 cal

DAY 10 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____
(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (a) : The area of brass sheet at 10°C = l_1b_1
The area of steel sheet at 20°C = l_2b_2
Given that $l_1b_1 = l_2b_2$ ...(i)
Let at temperature T°C, the areas of brass and steel sheets are same.
Length of brass sheet at T°C = $l_1[1 + \alpha_b\Delta T_b]$
Length of steel sheet at T°C = $l_2[1 + \alpha_s\Delta T_s]$
Breadth of brass sheet at T°C = $b_1[1 + \alpha_b\Delta T_b]$
Breadth of steel sheet at T°C = $b_2[1 + \alpha_s\Delta T_s]$
According to problem,
$l_1(1 + \alpha_b\Delta T_b) \times b_1(1 + \alpha_b\Delta T_b) = l_2(1 + \alpha_s\Delta T_s) \times b_2(1 + \alpha_s\Delta T_s)$
or $l_1b_1\,[1 + 19 \times 10^{-6} \times (10 - T)]^2$
$= l_2b_2\,[1 + 11 \times 10^{-6}\,(20 - T)]^2$
or $19 \times 10^{-6}(10 - T) = 11 \times 10^{-6}(20 - T)$

$$\therefore \quad T = -\frac{30}{8} = -3.75°C$$

2. (a) : According to Newton's law of cooling

$$\frac{T_1 - T_2}{t} = k\left(\frac{T_1 + T_2}{2} - T_s\right)$$

where T_s is the temperature of surroundings.
For the 1st case

$$\frac{75 - 65}{2} = k\left(\frac{75 + 65}{2} - 30\right)$$

$5 = k(40)$ ...(i)
For the IInd case

$$\frac{55 - 45}{t} = k\left(\frac{55 + 45}{2} - 30\right)$$

$$\frac{10}{t} = k(20) \quad \text{...(ii)}$$

Divide (i) by (ii), we get

$$\frac{t}{2} = \frac{40}{20} \quad \text{or} \quad t = 4 \text{ min}$$

3. (c)

4. (b): According to Newton's law of cooling.

$$\frac{\theta_1 - \theta_2}{t} = K\left[\frac{\theta_1 + \theta_2}{2} - \theta_0\right]$$

where θ_0 = surroundings temperature

$$\therefore \quad \frac{60 - 50}{10} = K\left[\frac{60 + 50}{2} - 25\right]$$

$1 = K \times 3.0$ ...(i)
After another 10 min, let the temperature be θ.

$$\therefore \quad \frac{50 - \theta}{10} = K\left[\frac{50 + \theta}{2} - 25\right] \quad \text{...(ii)}$$

Solving (i) and (ii), we get θ, = 42.85 °C.

5. (a) :

Heat flows through the slab in t s is

$$Q = \frac{KA(T_1 - T_2)t}{L} = \frac{K \times 0.36 \times (100 - 0) \times 3600}{0.1}$$

$$= \frac{K \times 0.36 \times 100 \times 3600}{0.1} \quad \text{...(i)}$$

So ice melted by this heat is

$$m_{ice} = \frac{Q}{L_f} \quad \text{...(ii)}$$

or $Q = m_{ice}\,L_f = 4.8 \times 3.36 \times 10^5$
From (i) and (ii), we get

$$\frac{K \times 0.36 \times (100 - 0) \times 3600}{0.1} = 4.8 \times 3.36 \times 10^5$$

$$K = \frac{4.8 \times 3.36 \times 10^5 \times 0.1}{0.36 \times 100 \times 3600}$$

$= 1.24$ J/m/s/°C

6. (d): According to Newton's law of cooling

$$\frac{(T_1 - T_2)}{t} = K\left(\frac{T_1 + T_2}{2} - T_s\right)$$

where T_s is the surroundings temperature. For the Ist case

$$\frac{(94°C - 86°C)}{2 \text{ min}} = K\left(\frac{(94°C + 86°C)}{2} - 20°C\right)$$

$$\frac{8°C}{2 \text{ min}} = K(70°C) \quad \text{...(i)}$$

For the IInd case

$$\frac{(71°C - 69°C)}{t} = K\left(\frac{71°C + 69°C}{2} - 20°C\right)$$

$$\frac{2°C}{t} = K(50°C) \quad \text{...(ii)}$$

Divide (i) by (ii), we get

$$\frac{8°C / 2\,\text{min}}{2°C / t} = \frac{K(70°C)}{K(50°C)}$$

$t = 0.7 = 42$ sec

7. (b)

8. (b): By Stefan's law
$Q = \sigma T^4$
The rate of dissipation of heat by a body of emissivity e is given by
$Q' = e\sigma T'^4$
Here, $T' = 2T$, $e = 0.25$
$\therefore \quad Q' = 0.25 \times \sigma(2T)^4 = 4\sigma T^4 = 4Q$

9. (d): According to Newton's law of cooling.

$$\frac{T_1 + T_2}{t} = K\left(\frac{T_1 + T_2}{2} - T_s\right)$$

where T_s is the surrounding temperature.
As per question,

$$\frac{(90 - 89)}{t_1} = K\left(\frac{90 + 89}{2} - 30\right)$$

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$$\frac{1}{t_1} = K(59.5) \quad ...(i)$$

$$\text{and } \frac{(60-59.5)}{t_2} = K\left(\frac{60+59.5}{2} - 30\right)$$

$$\frac{0.5}{t_2} = K(29.75) \quad ...(ii)$$

Divide (i) by (ii), we get

$$\frac{t_2}{0.5t_1} = \frac{59.5}{29.75}$$

$$\frac{t_2}{t_1} = 1 \text{ or } t_2 = t_1$$

10. (c) : Here, $T = 727°C = 1000$ K
$t = 0.3$ min $= 0.3 \times 60$ s $= 18$ s
$A = 0.1$ m^2
$\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}
According to Stefan's law
Heat radiated by a perfectly black body is
$H = \sigma AT^4 t$
$= (5.67 \times 10^{-8}$ W m^{-2} K$^{-4}) (0.1$ m$^2) (1000$ K$)^4 (18$ s$)$
$= 102060$ J

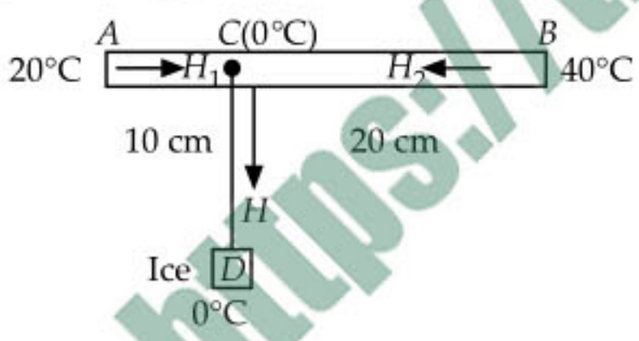
11. (d): Thermal resistance of $AC = \frac{L}{KA}$

$$= \frac{0.1}{336 \times 1 \times 10^{-4}} = \frac{10^3}{336} = R \text{ (suppose)}$$

Thermal resistance of $BC = \frac{0.2}{336 \times 10^{-4}} = 2R$

Temperature of $C = 0°C$

$$\therefore \quad H_1 = \frac{20}{R};\ H_2 = \frac{40}{2R} = \frac{20}{R}$$



$$\therefore \quad H = H_1 + H_2 = \frac{40}{R} = \frac{40 \times 336}{10^3}$$

$$= \frac{13440}{10^3} = 13.44 \text{ W}$$

Rate of melting of ice

$$= \frac{H}{L_f} = \frac{13.44/4.2}{80} \text{ g s}^{-1} = 40 \text{ mg s}^{-1}$$

12. (a) : According to Wein's displacement law,
$\lambda_{max} T = b$

$$\therefore \quad T = \frac{b}{\lambda_{max}} = \frac{2898 \text{ μm K}}{289.8 \text{ nm}}$$

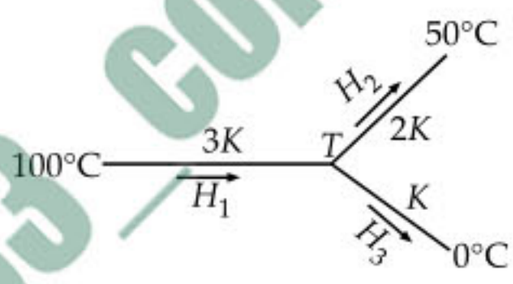
$$= \frac{2898 \times 10^{-6}}{289.8 \times 10^{-9} \text{ m}} = 10^4 \text{ K}$$

According to Stefan Boltzmann law,
Radiation intensity, $R = \sigma T^4$

$$R = (5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}) (10^4 \text{ K})^4 \quad ...(i)$$
$$= 5.67 \times 10^8 \text{ W m}^{-2}$$

13. (a) : Heat required by ice to convert totally into water at 100°C,
$Q_1 = 1 \times 80 + 1 \times 1 \times 100 = 180$ cal
Heat supplied by steam if it was to condense totally and convert into water at 100°C ...(ii)
$Q_2 = 1 \times 540 = 540$ cal
As $Q_2 > Q_1$, entire steam will not condense and final temperature = 100°C
Both water and steam will exist together in equilibrium at 100°C.

14. (a) : Let L and A be length and area of cross-section of each rod.



At steady state,
$H_1 = H_2 + H_3$

$$\frac{(100-T)(3K)A}{L} = \frac{(T-50)2KA}{L} + \frac{(T-0)KA}{L}$$

$$3(100 - T) = 2(T - 50) + T$$
$$300 - 3T = 2T - 100 + T$$
$$6T = 400$$

$$\text{or} \quad T = \frac{400}{6} = \frac{200}{3} °C$$

15. (b): According to Newton's law of cooling

$$\frac{T_2 - T_1}{t} = K\left[\frac{T_2 + T_1}{2} - T_S\right]$$

Where T_S is the temperature of the surroundings.

$$\therefore \quad \frac{70-50}{5} = K\left[\frac{70+50}{2} - 20\right] \quad ...(i)$$

$$4 = K[40]$$

$$\text{and } \frac{50-\theta}{10} = K\left[\frac{50+\theta}{2} - 20\right]$$

$$\frac{50-\theta}{10} = K\left[\frac{10+\theta}{2}\right] \quad ...(ii)$$

Divide (ii) by (i), we get

$$\frac{50-\theta}{10} \times \frac{1}{4} = \left[\frac{10+\theta}{2}\right] \times \frac{1}{40}$$

$$100 - 2\theta = 10 + \theta$$
$$\text{or} \quad 3\theta = 90 \text{ or } \theta = 30°C$$

16. (c) : Let $m_1 = m_2 = m_3 = m$
Let s_1, s_2, s_3 be the respective specific heats of the three liquids.
(i) When A and B are mixed, temperature of mixture = 16°C
As heat gained by A = heat lost by B
$\therefore \quad ms_1(16 - 12) = ms_2(19 - 16)$
$4s_1 = 3s_2$

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(ii) When B and C are mixed, temperature of mixture = 23°C.
A heat gained by B = heat lost by C
$\therefore \quad ms_2(23-19) = ms_3(28-23)$
$4s_2 = 5s_3$
From eqs. (i) and (ii), we get

$$s_1 = \frac{3}{4}s_2 = \frac{15}{16}s_3$$

When A and C are mixed, suppose temperature of mixture = T
heat gained by A = heat lost by C

$$ms_1(T-12) = ms_3(28-T)$$

$$\frac{15}{16}s_3(T-12) = s_3(28-T)$$

$$15T - 180 = 448 - 16T$$

$$T = \frac{628}{31} = 20.2°C$$

17. (b): Here, $\lambda_{m_1} = \lambda_m$, $T_1 = 2000$ K
$\lambda_{m_2} = ?$, $T_2 = 3000$ K
According to Wein's displacement law,
$\lambda m_2 T_2 = \lambda_{m_1} T_1$

$$\lambda_{m_2} = \lambda_{m_1}\frac{T_1}{T_2} = \lambda_m \times \frac{2000}{3000} = \frac{2}{3}\lambda_m$$

18. (c): According to Newton's law of cooling

$$\frac{T_1 - T_2}{t} = K\left[\frac{T_1 + T_2}{2} - T_s\right]$$

where T_s is the temperature of the surroundings.
For 1st case

$$\frac{60-55}{30} = K\left[\frac{60+55}{2} - 45\right] \quad ...(i)$$

Similarly, for 2nd case

$$\frac{55-50}{t} = K\left[\frac{55+50}{2} - 45\right] \quad ...(ii)$$

Dividing Eq. (i) by Eq.(ii), we get

$$\frac{\frac{5}{30}}{\frac{5}{t}} = \frac{12.5}{7.5} \text{ or } \frac{t}{30} = \frac{12.5}{7.5} \text{ or } t = \frac{12.5}{7.5} \times 30 = 50 \text{ s}$$

19. (a): Here,

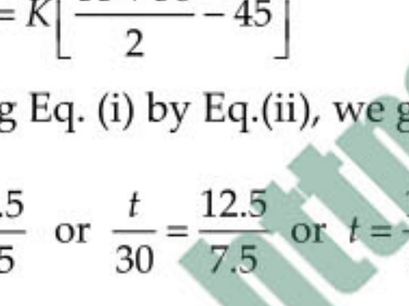
$$C(\text{kJ K}^{-1}\text{ kg}^{-1}) = 32\left(\frac{T}{400}\right)^3$$

$m = 100$ g $= 0.1$ kg
Work done to cool the vessel = Amount of heat taken out from metal while cooling it from 20 K to 4 K.

$$\therefore \quad W = -\int_{20}^{4} mC\,dT = -\int_{20}^{4} 0.1 \times \left(32\frac{T^3}{400^3}\right)dT$$

$$= -\frac{0.1 \times 32}{400^3}\left[\frac{T^4}{4}\right]_{20}^{4} = 0.001996 \text{ kJ} = 0.002 \text{ kJ}$$

20. (b):



Let T be the temperature at the junction.
Let L and A be the length and area of cross-section of each rod respectively.
$\therefore$ Heat current from Y to X is

$$H_1 = \frac{KA(90°C - T)}{L}$$

Heat current from Z to X is

$$H_2 = \frac{KA(90°C - T)}{L}$$

Heat current from X to W is

$$H_3 = \frac{KA(T - 0°C)}{L}$$

At the junction X,
$H_1 + H_2 = H_3$
$\therefore \quad 90°C - T + 90°C - T = T$
or $\quad 3T = 180°C$ or $T = 60°C$

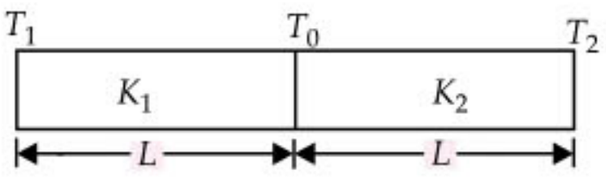
21. (c): Here, $T_1 = 27°C$, $L_{T_1} = 5.23$ m,
$L_{T_2} = 5.24$ m, $\alpha = 1.2 \times 10^{-5}\,°C^{-1}$
As $\quad L_{T_2} = L_{T_1}(1 + \alpha(T_2 - T_1))$

$$\therefore \quad 5.24 = 5.23(1 + 1.2 \times 10^{-5}(T_2 - 27))$$

$$T_2 = \frac{5.24 - 5.23}{5.23 \times 1.2 \times 10^{-5}} + 27 = 159 + 27 = 186\ °C$$

22. (a): Thermal stress = $Y\,\alpha\,\Delta T$

23. (a):



Let L and A be length and area of cross-section of each bar respectively.
Let T_0 be temperature of the junction of the two bars.
$\therefore$ Heat current through the bar 1 is

$$H_1 = \frac{K_1 A(T_1 - T_0)}{L}$$

Heat current through the bar 2 is

$$H_2 = \frac{K_2 A(T_0 - T_2)}{L}$$

At steady state, $H_1 = H_2$

$$\therefore \quad \frac{K_1 A(T_1 - T_0)}{L} = \frac{K_2 A(T_0 - T_2)}{L}$$

$$K_1(T_1 - T_0) = K_2(T_0 - T_2)$$
$$K_1T_1 - K_1T_0 = K_2T_0 - K_2T_2$$
$$K_1T_0 + K_2T_0 = K_1T_1 + K_2T_2$$
$$T_0(K_1 + K_2) = K_1T_1 + K_2T_2$$

$$T_0 = \frac{K_1T_1 + K_2T_2}{(K_1 + K_2)}$$

24. (d): Here,
Mass of water, $m_w = 100$ g
Mass of ice, $m_i = 10$ g
Specific heat of water, $s_w = 1$ cal $g^{-1}\,°C^{-1}$
Latent heat of fusion of ice, $L_{f_i} = 80$ cal g^{-1}
Let T be the final temperature of the mixture.
Amount of heat lost by water

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$= m_w s_w (\Delta T)_w = 100 \times 1 \times (50 - T)$
Amount of heat gained by ice
$= m_i L_{f_i} + m_i s_w (\Delta T)_i = 10 \times 80 + 10 \times 1 \times (T - 0)$
According to principle of calorimetry
Heat lost = Heat gained
$100 \times 1 \times (50 - T) = 10 \times 80 + 10 \times 1 \times (T - 0)$
$500 - 10T = 80 + T$
$11T = 420$ or $T = 38.2°C$

25. (c) : Change in length of the brass rod is
$\Delta L_b = \alpha_b L_b \Delta T$
$= 2.0 \times 10^{-5} °C^{-1} \times 50 \text{ cm} \times (250 °C - 50 °C) = 0.2 \text{ cm}$
Change in length of the steel rod is
$\Delta L_s = \alpha_s L_s \Delta T$
$= 1.2 \times 10^{-5} °C^{-1} \times 50 \text{ cm} \times (250°C - 50°C) = 0.12 \text{ cm}$
$\therefore$ Change in length of the combined rod
$= \Delta L_b + \Delta L_s = 0.2 \text{ cm} + 0.12 \text{ cm} = 0.32 \text{ cm}$

26. (a) : According to an ideal gas equation
$PV = nRT$ ...(i)
At constant pressure,
$P\Delta V = nR\Delta T$ ...(ii)
Dividing (ii) by (i), we get
$$\frac{\Delta V}{V} = \frac{\Delta T}{T} \quad ...(iii)$$
If γ represents volume thermal expansion coefficient of an ideal gas, then
$$\frac{\Delta V}{V} = \gamma \Delta T \quad ...(iv)$$
Comparing (iii) and (iv), we get
$$\gamma = \frac{1}{T}$$

27. (d): According to Newton's law of cooling, the rate of loss of heat is directly proportional to the difference of temperature of the body and the surroundings.
$$i.e. \; -\frac{dQ}{dt} = k(T - T_s)$$
where T is the temperature of the body and T_s is the temperature of the surroundings and k is a positive constant depending on the area and nature of the surface of the body.

28. (d): Let V be the volume of sphere of radius R at temperature T. Then
$$V = \frac{4}{3}\pi R^3$$
Coefficient of linear expansion = α
$\therefore$ Coefficient of volume expansion = $\gamma = 3\alpha$
Increase in volume of the sphere with rise in temperature ΔT is
$$\Delta V = \gamma V \Delta T = 3\alpha \frac{4}{3}\pi R^3 \Delta T = 4\pi R^3 \alpha \Delta T$$

29. (d): In convection process, the heat is transferred by the bodily motion of the heated particles. It is not so in case of warming of glass bulb due to filament heating. Infact, warming of glass bulb is due to radiation.

30. (b): Among the given liquids water shows anomalous expansion.

31. (a)

32. (a) : In the given P-T diagram,
Region I - Liquid
Region II - Solid
Region III- Vapour

33. (b): Let F be tension developed in the wire.
$$\therefore \quad Y = \frac{F/A}{\Delta L/L}$$
As $\Delta L = L\alpha\Delta T$
$$\therefore \quad Y = \frac{F}{A\alpha\Delta T} \text{ or } F = YA\alpha\Delta T$$
Here, $\alpha = 2.0 \times 10^{-5} °C^{-1}$, $Y = 9 \times 10^{10} \text{ N m}^{-2}$
$A = \pi(1 \times 10^{-3})^2 m^2$,
$\Delta T = 66°C$
$\therefore \quad F = 9 \times 10^{10} \times \pi(1 \times 10^{-3})^2 \text{ m}^2 \times 2.0 \times 10^{-5} \times 66$
$= 3.7 \times 10^2 \text{ N}$

34. (c) : According to Newton's law of cooling
$$\frac{T_1 - T_2}{t} = k\left[\frac{T_1 + T_2}{2} - T_s\right]$$
Where T_s is the temperature of the surroundings.
$$\therefore \quad \frac{80 - 50}{300} = k\left[\frac{80 + 50}{2} - 20\right]$$
$$\frac{30}{300} = k[65 - 20] \quad ...(i)$$
If the body takes t seconds to cool from 60°C to 30°C, then
$$\frac{60 - 30}{t} = k\left(\frac{60 + 30}{2} - 20\right)$$
$$\frac{30}{t} = k[45 - 20] \quad ...(ii)$$
Divide (i) by (ii), we get
$$\frac{30}{300} \times \frac{t}{30} = \frac{45}{25} \text{ or } t = \frac{45}{25} \times 300 = 540 \text{ s}$$

35. (c) : As $\rho_{T_2} = \frac{\rho_{T_1}}{1 + \gamma\Delta T} = \frac{\rho_{T_1}}{1 + \gamma(T_2 - T_1)}$
Here, $T_1 = 4°C$, $T_2 = 100°C$
$\rho_{T_1} = 1000 \text{ kg m}^{-3}$, $\rho_{T_2} = 958.4 \text{ kg m}^{-3}$
$$\therefore \quad 958.4 = \frac{1000}{1 + \gamma(100 - 4)}$$
$$958.4 = \frac{1000}{1 + 96\gamma} \text{ or } 1 + 96\gamma = \frac{1000}{958.4}$$
$$96\gamma = \frac{1000}{958.4} - 1 = \frac{41.6}{958.4}$$
$$\gamma = \frac{41.6}{958.4 \times 96} = 4.5 \times 10^{-4} °C^{-1}$$

36. (a) : The latent heat of vaporisation of a substance is always greater than its latent heat of fusion.

37. (a) : For a cooking utensil, specific heat should be low so that it absorbs lesser heat, thermal conductivity should be high so that whole of heat absorbed is transmitted to things being cooked.

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38. (c) : In a pressure cooker, cooking is faster because the increase of pressure increases the boiling point.

39. (c) : Rate of loss of heat from a body is directly proportional to the surface area of the body. For a given mass of a material, the surface area of a circular plate is maximum while of sphere is minimum. Hence, the plate will cool fastest and sphere the slowest.

40. (a) : The heat from hot milk spread on the table is transferred to the surroundings by conduction, convection and radiation. According to Newton's law of cooling the temperature of milk falls exponentially with time.

41. (c) : Here,

Length of each side, $l = 20\ \text{cm} = 20 \times 10^{-2}\ \text{m}$

Thickness, $x = 5\ \text{cm} = 5 \times 10^{-2}\ \text{m}$

Total surface area through which heat enters into the box,

$A = 6l^2 = 6 \times (20 \times 10^{-2}\ \text{m})^2 = 24 \times 10^{-2}\ \text{m}^2$

Temperature difference, $\Delta T = 50°\text{C} - 0°\text{C} = 50°\text{C}$

Thermal conductivity, $K = 0.01\ \text{J s}^{-1}\ \text{m}^{-1}\ °\text{C}^{-1}$

Time, $t = 10\ \text{h} = 10 \times 60 \times 60\ \text{s} = 36 \times 10^3\ \text{s}$

$L_f = 335 \times 10^3\ \text{J kg}^{-1}$

Total heat entering the box through all the six faces is

$$Q = \frac{KA\Delta Tt}{x}$$

$$= \frac{0.01\ \text{J s}^{-1}\text{m}^{-1}\text{°C}^{-1} \times 24 \times 10^{-2}\text{m}^2 \times 50°\text{C} \times 36 \times 10^3\text{s}}{5 \times 10^{-2}\ \text{m}}$$

$= 86400\ \text{J}$ ...(i)

Let m kg of ice melts in this time.

$\therefore \quad Q = mL_f$ ...(ii)

From (i) and (ii), we get

$$m = \frac{86400\ \text{J}}{335 \times 10^3\ \text{J kg}^{-1}} = 0.258\ \text{kg}$$

$\therefore$ Amount of ice left= (5 – 0.258) kg

= 4.742 kg = 4.7 kg

42. (a) : Time period of the simple pendulum is

$$T = 2\pi\sqrt{\frac{L}{g}} \qquad ...(i)$$

where L is the effective length of the pendulum. With increase in temperature, the effective length (L) of simple pendulum increases even though its centre of mass still remains at the centre of the bob.

From (i), $T \propto \sqrt{L}$

So T increases as temperature increases.

43. (c) : A cavity in a material expands in exactly the same way as if the cavity were filled with material. Thus, both spheres will expand by the same amount.

44. (a) : Here,

Triple point of water on scale A = 200 A

Triple point of water on scale B = 400 B

Triple point of water on kelvin scale = 273.16 K

As per question

200 A = 350 B = 273.16 K

$$\therefore \quad 1\ \text{A} = \frac{273.16}{200}\ \text{K}$$

$$\text{and} \quad 1\ \text{B} = \frac{273.16}{400}\ \text{K}$$

If T_A and T_B represent the triple point of water on two scales A and B, then

$$\frac{273.16}{200}T_A = \frac{273.16}{400}T_B \quad \text{or} \quad \frac{T_A}{T_B} = \frac{200}{400} = \frac{1}{2} \quad \text{or} \quad T_A = \frac{1}{2}T_B$$

45. (a) : If S calorie of heat is received from the sun per cm^2 per minute, the heat collected by the lens of radius 2.5 cm in 20 minutes is

$Q_1 = S \times A \times t = S \times \pi \times (2.5)^2 \times (20) = (392.5)S$ cal

Heat required to melt 10 g of ice is

$Q_2 = mL = 10 \times 80 = 800$ cal

According to given problem $Q_1 = Q_2$

$\therefore \quad 392.5S = 800$ or $S = 2.04\ \text{cal cm}^{-2}\ \text{min}^{-1}$

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Thermodynamics

Temperature

Temperature is that property of a body which helps us to decide the degree of its hotness. When two bodies at different temperatures are kept in contact, in absence of any other effect, heat flows from the body at higher temperature to the one at lower temperature always. This flow occurs till the temperature of the two bodies become equal. This state is also referred to as **thermal equilibrium.**

Zeroth Law of Thermodynamics

If two systems A and B are each in thermal equilibrium with a third system C, then A and B will be in thermal equilibrium with each other.

Heat

Heat is the energy transferred between a system and its environment because of a temperature difference that exists between them. It is a scalar quantity. Its SI unit is joule. It is path dependent.

Work

The work done by the system is

$$W = \int dW = \int_{V_i}^{V_f} PdV$$

Here V_i and V_f referred to the change in volume from state i to state f.

During the change in volume, the pressure and temperature of the system also change. It is a scalar quantity. Its SI unit is joule. It is path dependent. In P-V diagram (also called indicator diagram) the area under P-V curve represents work done.

Internal Energy

Internal energy of a system is the energy possessed by the system due to molecular motion and molecular configuration.

Change in internal energy is path independent and depends only on the initial and final states of the system.

The internal energy of an ideal gas is only dependent upon temperature whereas that of a real gas it is a function of both temperature and volume.

Thermodynamic Variables

These are macroscopic physical quantities like pressure (P), volume (V) and temperature (T) etc. which are used to describe the state of the system. The relation between these variables is called **equation of state**. Heat and work are not thermodynamic variables.

Thermodynamic variables are of two kinds :

- Extensive
- Intensive

Internal energy U, volume V, total mass M are extensive variables. Pressure P, temperature T and density ρ are intensive variables.

First law of Thermodynamics

First law of thermodynamics is simply a restatement of principle of conservation of energy. Imagine a gaseous system for which P(pressure), V(volume) and T(temperature) are related by certain equation of state and is undertaken through a process. If ΔQ, ΔU and ΔW represent the heat given to the system, change in internal energy and work done by the system respectively. During the process the first law of thermodynamic states that

$$\Delta Q = \Delta U + \Delta W$$

Sign Convention

- Heat absorbed by the system is taken as positive while the heat lost by the system is taken as negative.
- Work done by the system is taken as positive while work done on a system is taken as negative.
- The increase in internal energy of the system is taken as positive while decrease in internal energy is taken as negative.

Isothermal Process

For such a process temperature remains constant throughout the process. Hence PV = constant as T is constant. Work is done at the same rate as heat is supplied, hence there is no increase of internal energy. Due to this, $\Delta U = 0$ and thus $\Delta Q = \Delta W$.

Work done during an isothermal process

$$W = \mu RT \ln\left(\frac{V_2}{V_1}\right)$$

$$W = \mu RT \ln\left(\frac{P_1}{P_2}\right)$$

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The slope of isothermal curve on a P-V diagram at any point on the curve is given by

$$\frac{dP}{dV} = \frac{-P}{V}$$

In an isothermal expansion the gas absorbs heat and does work and in an isothermal compression work is done on the gas by the environment and heat is released.

Adiabatic Process

An adiabatic process is one that occurs so rapidly or occurs in a system that is so well insulated that no transfer of energy as heat occurs between the system and its environment.

Equation of adiabatic process,

$PV^{\gamma} = \text{constant}$

$TV^{\gamma-1} = \text{constant}$

where, $\gamma = \left(\frac{C_P}{C_V}\right)$ is called adiabatic exponent.

Work done during an adiabatic process

$$W = \frac{(P_1V_1 - P_2V_2)}{(\gamma - 1)} = \mu R \frac{(T_1 - T_2)}{\gamma - 1}$$

The slope of adiabatic curve on a P-V diagram at any point on the curve is given by

$$\frac{dP}{dV} = -\gamma\left(\frac{P}{V}\right)$$

In an adiabatic expansion temperature of the gas will fall ($T_2 < T_1$) while in adiabatic compression temperature of the gas will rise ($T_2 > T_1$).

Second Law of Thermodynamics

Kelvin-Planck statement : No process is possible whose sole result is the absorption of heat from a reservoir and the complete conversion of the heat into work.

Clausius statement : No process is possible whose sole result is the transfer of heat from a colder object to a hotter object.

Reversible and Irreversible Processes

Reversible process : A reversible process is one which can be retraced in the opposite direction.

A quasi-static isothermal expansion of an ideal gas in a cylinder fitted with a frictionless movable piston is an example of a reversible process.

Irreversible process : An irreversible process is one which cannot be retraced back in the opposite direction.

All spontaneous processes of nature are irreversible processes. *e.g.* transfer of heat from a hot body to a cold body, diffusion of gases, etc. are all irreversible processes.

Carnot Engine

Carnot engine is a reversible heat engine operating between two temperatures T_1 (source) and T_2 (sink).

Carnot cycle : Carnot engine works in series of operations. The operations consist of an isothermal expansion and then adiabatic expansion. Further operations are isothermal compression and adiabatic compression so that the working substance is back at the initial state at the end of each cycle. This cycle of operations is called Carnot cycle.

The efficiency of a Carnot engine is given by

$$\eta = 1 - \frac{T_2}{T_1}$$

The efficiency of Carnot engine depends on the temperature of source (T_1) and temperature of the sink (T_2) , but does not depend upon the nature of the working substance.

Carnot theorem : No heat engine operating between two given temperatures can be more efficient than a Carnot engine operating between the same two temperatures.

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EXAM DRILL

1. A gas at pressure 6×10^5 N m^{-2} and volume 1 m^3 and its pressure falls to 4×10^5 N m^{-2}. When its volume is 3 m^3. Given that the indicator diagram is a straight line, work done by the system is
(a) 6×10^5 J (b) 3×10^5 J
(c) 4×10^5 J (d) 10×10^5 J

2. The work of 146 kJ is performed in order to compress one kilo mole of a gas adiabatically and in this process the temperature of the gas increases by 7°C. The gas is ($R = 8.3$ J mol^{-1} K^{-1})
(a) diatomic
(b) triatomic
(c) a mixture of monoatomic and diatomic
(d) monoatomic

3. The temperatures of inside and outside of a refrigerator are 273 K and 303 K respectively. Assuming that the refrigerator cycle is reversible, for every joule of work done, the heat delivered to the surroundings will be nearly.
(a) 10 J (b) 20 J
(c) 30 J (d) 50 J

4. In a given process of an ideal gas, $dW = 0$ and $dQ < 0$. Then for the gas
(a) the temperature will decrease
(b) the volume will increase
(c) the pressure will remain constant
(d) the temperature will increase

5. An ideal gas at a pressure of 1 atmosphere and temperature of 27°C is compressed adiabatically until its pressure becomes 8 times the initial pressure. Then the final temperature is $\left(\gamma = \frac{3}{2}\right)$
(a) 627°C (b) 527°C
(c) 427°C (d) 327°C

6. An ideal Carnot engine whose efficiency is 40% receives heat at 500 K. If the efficiency is to be 50%, the in take temperature for the same exhaust temperature is
(a) 600 K (b) 900 K
(c) 700 K (d) 800 K

7. A gas expands with temperature according to the relation $V = KT^{2/3}$. Calculate work done when the temperature changes by 60 K?
(a) $10R$ (b) $30R$
(c) $40R$ (d) $20R$

8. A Carnot engine whose sink is at 300 K has an efficiency of 40%. By how much should the temperature of source be increased so as to increase its efficiency by 50% of original efficiency?
(a) 380 K (b) 275 K
(c) 325 K (d) 250 K

9. An ideal gas heat engine operates in Carnot cycle between 227°C and 127°C. It absorbs 6×10^4 cal of heat at higher temperature. Amount of heat converted to work is
(a) 2.4×10^4 cal (b) 6×10^4 cal
(c) 1.2×10^4 cal (d) 4.8×10^4 cal

10. A cylinder containing one gram molecule of the gas was compressed adiabatically until its temperature rise from 27°C to 97°C. The heat produced in the gas ($\gamma = 1.5$) is
(a) 250.6 cal (b) 276.7 cal
(c) 298.5 cal (d) 320 cal

11. An electric heater supplies heat to a system at a rate of 120 W. If system performs work at a rate of 80 J s^{-1}, the rate of increase in internal energy is
(a) 30 J s^{-1} (b) 40 J s^{-1}
(c) 50 J s^{-1} (d) 60 J s^{-1}

12. One mole of an ideal gas undergoes an isothermal change at temperature T so that its volume V is doubled. R is the molar gas constant. Work done by the gas during this change is
(a) $RT\ln 4$ (b) $RT\ln 2$
(c) $RT\ln 1$ (d) $RT\ln 3$

13. Two spheres A and B have diameters in the ratio 1 : 2, densities in the ratio 2 : 1 and specific heats in the ratio 1 : 3, the ratio of their thermal capacities is
(a) 1 : 6 (b) 1 : 12
(c) 1 : 3 (d) 1 : 4

14. How much heat energy in joules must be supplied to 14 g of nitrogen at room temperature to raise its temperature by 40°C at constant pressure?
(Mol. wt. of $N_2 = 28$ g)
(a) $50R$ (b) $60R$
(c) $70R$ (d) $80R$

15. If R is universal gas constant, the amount of heat needed to raise the temperature of 2 moles of an ideal monoatomic gas from 273 K to 373 K when no work is done is
(a) $100R$ (b) $150R$
(c) $300R$ (d) $500R$

16. When heat energy of 1500 J is supplied to a gas at constant pressure, 2.1×10^5 N m^{-2}, there was an increase in its volume equal to 2.5×10^{-3} m^3. The increase in its internal energy is
(a) 450 J (b) 525 J
(c) 975 J (d) 2025 J

17. A monoatomic gas is compressed adiabatically to $\frac{1}{4}$ th of its original volume, the final pressure of gas in terms of initial pressure P is
(a) 7.08 P (b) 8.08 P
(c) 9.08 P (d) 10.08 P

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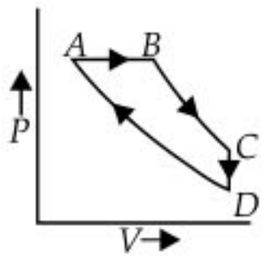
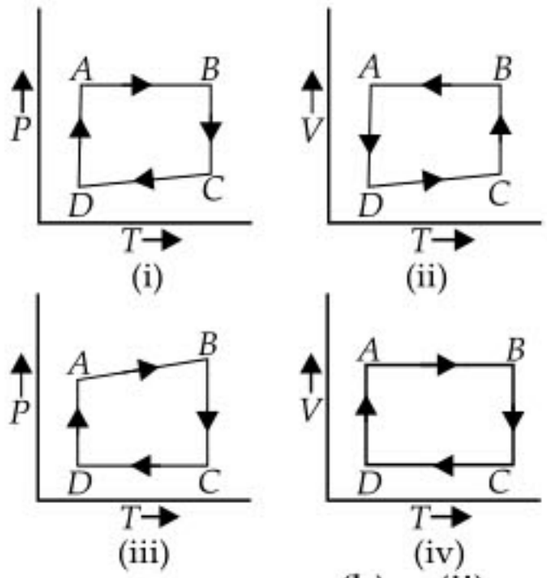
18. An ideal gas is subjected to a cyclic process $ABCD$ as depicted in the P-V diagram given below.



Which of the following curves represent the equivalent cyclic process?



(a) (i) (b) (ii)
(c) (iii) (d) (iv)

19. What amount of heat must be supplied to 35 g of oxygen at room temperature to raise its temperature by 80 °C at constant volume (molecular mass of oxygen is 32 and $R = 8.3$ J mol^{-1} k^{-1})
(a) 1.52 kJ (b) 3.23 kJ
(c) 1.81 kJ (d) 1.62 kJ

20. A Carnot engine whose low temperature reservoir is at 7°C has an efficiency of 50%. It is desired to increase the efficiency to 70%. By how many degrees should be temperature of the high temperature reservoir be increased?
(a) 933 K (b) 432 K
(c) 373 K (d) 267 K

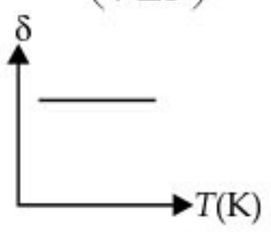
21. The inside and outside temperatures of a refrigerator are 273 K and 303 K respectively. Assuming that refrigerator cycle is reversible for every joule of work done, the heat delivered to the surroundings will be
(a) 10 J (b) 20 J
(c) 30 J (d) 50 J

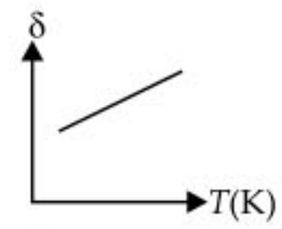
22. Six moles of an ideal gas performs a cycle shown in figure. If the temperature are $T_A = 600$ K, $T_B = 800$ K, $T_C = 2200$ K and $T_D = 1200$ K, the work done per cycle is approximately

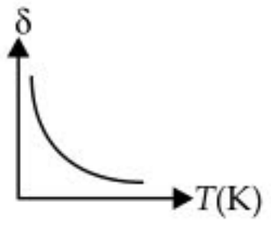
(a) 20 kJ (b) 30 kJ
(c) 40 kJ (d) 60 kJ

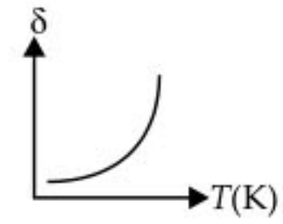
23. An ideal gas with pressure P, volume V and temperature T is expanded isothermally to a volume $2V$ and a final pressure P_I. The same gas is expanded adiabatically to a volume $2V$, the final pressure is P_A. In terms of the ratio of the two specific heats for the gas γ, the ratio P_I/P_A is
(a) $2^{\gamma-1}$ (b) $2^{1-\gamma}$
(c) 2^{γ} (d) 2γ

24. An ideal gas is initially at temperature T and volume V. Its volume is increased by ΔV, due to an increase in temperature ΔT, pressure remaining constant. The quantity $\delta\left(\frac{\Delta V}{V\Delta T}\right)$ varies with temperature as

(a) 

(b) 

(c) 

(d) 

25. An engine has an efficiency of 1/6. When the temperature of sink is reduced by 62°C, its efficiency is doubled. Temperature of the source is
(a) 37°C (b) 62°C
(c) 124°C (d) 99°C

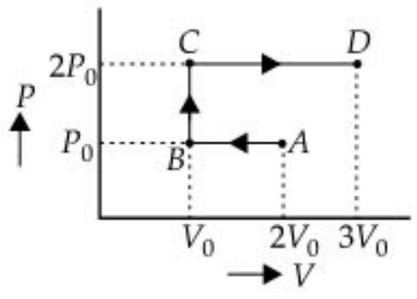
26. The pressure and density of a diatomic gas $\left(\gamma = \frac{7}{5}\right)$ change adiabatically from (P, ρ) to (P', ρ').
If $\frac{\rho'}{\rho} = 32$, then $\frac{P'}{P}$ is
(a) $\frac{1}{128}$ (b) 32
(c) 128 (d) 256

27. P–V diagram of a diatomic gas is a straight line passing through origin. The molar heat capacity of the gas in the process will be
(where R is universal gas constant)
(a) $4R$ (b) $3R$
(c) $\frac{4}{3}R$ (d) $2.5R$

28. A Carnot engine whose efficiency is 40%, takes in heat from a source maintained at a temperature of 500 K. It is desired to have an engine of efficiency 60%. Then, the intake temperature for the same exhaust (sink) temperature must be
(a) 1200 K (b) 750 K
(c) 600 K (d) 800 K

29. An ideal gas is taken through a cyclic thermodynamical process through four steps. The amounts of heat involved in these steps are: $Q_1 = 5960$ J, $Q_2 = -5585$ J, $Q_3 = -2980$ J, $Q_4 = 3645$ J; respectively. The corresponding works involved are: $W_1 = 2200$ J, $W_2 = -825$ J, $W_3 = -1100$ J and W_4 respectively. The value of W_4 is
(a) 1315 J (b) 275 J
(c) 765 J (d) 675 J

30. P–V diagram of an ideal gas is as shown in figure. Work done by the gas in the process $ABCD$ is



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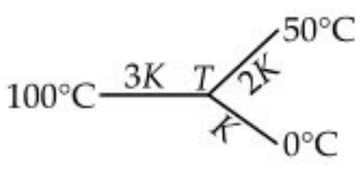
(a) $4P_0V_0$ (b) $2P_0V_0$
(c) $3P_0V_0$ (d) P_0V_0

31. 1 g of ice is mixed with 1 g of steam. After thermal equilibrium is reached, the temperature of mixture is
(a) 100°C (b) 55°C
(c) 75°C (d) 0°C

32. Two cylinders A and B, fitted with pistons. A and B contain equal moles of an ideal monoatomic gas at 400 K. Piston in A is free to move, while piston in B is held fixed. Same amount of heat is given to the gas in each cylinder. If the rise in temperature of the gas in A is 42 K, then the increase in the temperature of the gas in B is, $\left(\gamma = \frac{5}{3}\right)$
(a) 35 K (b) 42 K
(c) 70 K (d) 21 K

33. A diatomic ideal gas is used in a Carnot engine as the working substance. If during the adiabatic expansion part of the cycle, the volume of the gas increases from V to $32V$, the efficiency of the engine is
(a) 0.75 (b) 0.99
(c) 0.25 (d) 0.5

34. Three rods of same dimensions have thermal conductivities $3K$, $2K$ and K respectively. They are arranged as shown below



What will be the temperature T of the junction?
(a) $\frac{200}{3}$°C (b) $\frac{100}{3}$°C
(c) 75°C (d) $\frac{50}{3}$°C

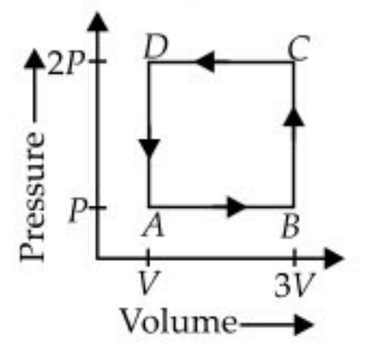
35. 5 moles of hydrogen $\left(\gamma = \frac{7}{5}\right)$ initially at STP are compressed adiabatically so that its temperature becomes 400°C. The increase in the internal energy of the gas is
($R = 8.30$ J mol^{-1} K^{-1})
(a) 21.5 kJ (b) 41.5 kJ
(c) 65.5 kJ (d) 80.5 kJ

36. 5.6 litre of helium gas at STP is adiabatically compressed to 0.7 litre. Taking the initial temperature to be T_1, the work done in the process is
(a) $-\frac{9}{8}RT_1$ (b) $\frac{3}{2}RT_1$
(c) $\frac{15}{8}RT_1$ (d) $\frac{9}{2}RT_1$

37. A clock pendulum made of invar has a period of 0.5 s at 20°C. If the clock is used in a climate where the temperature averages 30°C, how much time does the clock lose in each oscillation? (For invar, $\alpha = 9 \times 10^{-7}$°C^{-1} and g = constant)
(a) 2.25×10^{-6} s (b) 2.5×10^{-7} s
(c) 5×10^{-7} s (d) 1.125×10^{-6} s

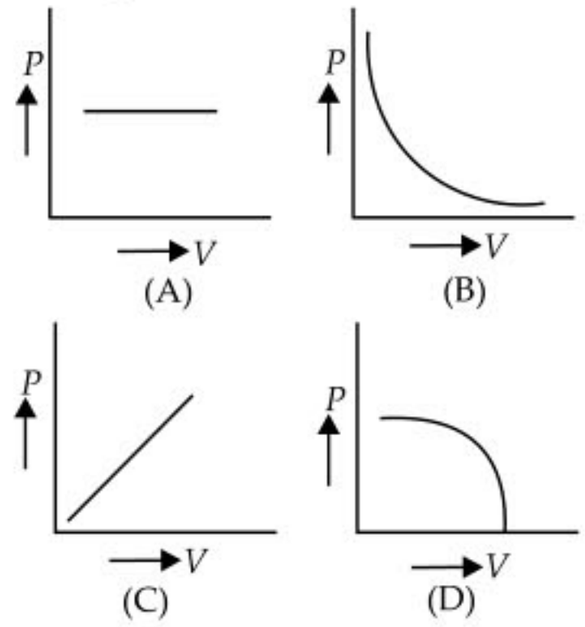
38. One mole of an ideal gas ($\gamma = 1.4$) is adiabatically compressed so that its temperature rises from 27°C to 35°C. The change in the internal energy of the gas is (given $R = 8.3$ J^{-1}mole^{-1} K^{-1})
(a) – 166 J (b) 166 J
(c) – 168 J (d) 168 J

39. A thermodynamic system is taken through the cycle $ABCD$ as shown in figure. Heat rejected by the gas during the cycle is
(a) $2PV$
(b) $4PV$
(c) $\frac{1}{2}PV$
(d) PV



40. When an ideal gas with pressure P and volume V is compressed isothermally to one fourth of its volume, the pressure is P_1. When the same gas is compressed polytropically according to the equation $PV^{1.5}$ = constant to one fourth of its initial volume, the pressure is P_2. The ratio $\frac{P_1}{P_2}$ is
(a) $\frac{1}{2}$ (b) $\frac{1}{2^{1.5}}$
(c) 2 (d) $2^{1.5}$

41. Which of the following P-V diagrams, best represents an isothermal process?



(a) A (b) B
(c) C (d) D

42. One mole of an ideal monoatomic gas at temperature T_0 expands slowly according to the law $\frac{P}{V}$. If the final temperature is $2T_0$ heat supplied the gas is
(a) $2RT_0$ (b) RT_0
(c) $\frac{3}{2}RT_0$ (d) $\frac{1}{2}RT_0$

43. What is the change in internal energy of one mole of a gas, when volume changes from V to $2V$ at constant pressure P?
(a) $\frac{R}{(\gamma - 1)}$ (b) PV
(c) $\frac{PV}{(\gamma - 1)}$ (d) $\frac{\gamma PV}{(\gamma - 1)}$

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44. The efficiency of Carnot's heat engine is 0.5 when the temperature of the source is T_1 and that of sink is T_2. The efficiency of another Carnot's heat engine is also 0.5. The temperature of source and sink of the second engine are respectively

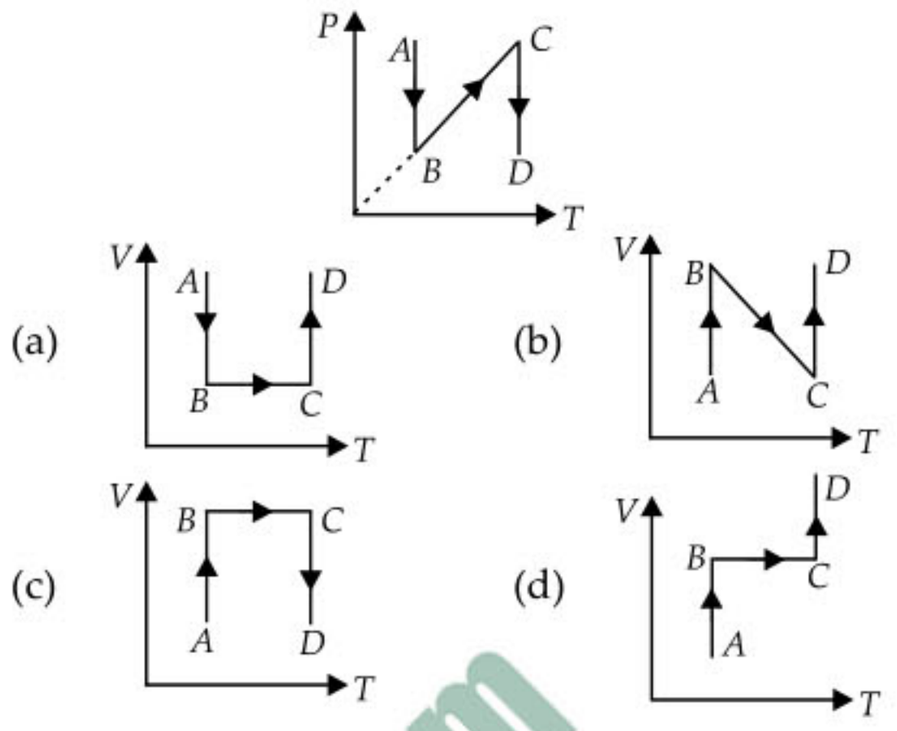
(a) $2T_1, 2T_2$

(b) $2T_1, \frac{T_2}{2}$

(c) $T_1 + 5, T_2 - 5$

(d) $T_1 + 10, T_2 - 10$

45. P-T diagram is shown in figure. Choose the corresponding V-T diagram.



DAY 11 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ

Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____

(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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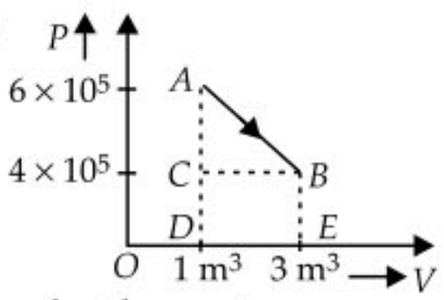
HINTS & SOLUTIONS

1. (d) :



Work done by the system

= area under $P - V$ diagram

= area of rectangle $BCDE$ + area of ΔABC

$$= 4\times10^5\times2+\frac{2\times10^5\times2}{2}$$

$$W = 10\times10^5\ \text{J}$$

2. (a) : For adiabatic process,

$dQ = 0$

So, $dU = -\Delta W$

or $\mu C_V dT = +146\times10^3\ \text{J}$

or $\dfrac{\mu f R}{2}\times7 = 146\times10^3$ $\left(\because C_V = \dfrac{fR}{2}\right)$

($f \rightarrow$ Degree of freedom)

$$\Rightarrow \quad \frac{10^3\times f\times8.3\times7}{2} = 146\times10^3$$

$f = 5.02 \approx 5$

Therefore, gas is diatomic.

3. (a) : Using $\beta = \dfrac{Q_2}{W} = \dfrac{T_L}{T_H - T_L}$

$T_L = 273$ K, $T_H = 303$ K and $W = 1$ J

$$\therefore \quad Q_2 = \frac{273}{303-273}\times1 = \frac{273}{30} \cong 9\ \text{J}$$

Hence, heat delivered to surroundings,

$Q_1 = Q_2 + W = 9 + 1 = 10$ J

4. (a) : From first law of thermodynamics

$dQ = dU + dW$

$dQ = dU$ (If $dW = 0$)

Since, $dQ < 0$

$\therefore \quad dU < 0$

or $U_{\text{final}} < U_{\text{initial}}$

Hence, temperature will decrease.

5. (d) : Here, $P_1 = 1$ atm, $T_1 = 27°C$

$= 27 + 273 = 300$ K

$P_2 = 8P_1$, $T_2 = ?$, $\gamma = \dfrac{3}{2}$

As changes are adiabatic,

$$\therefore \quad P_1^{\gamma-1}T_1^{-\gamma} = P_2^{\gamma-1}T_2^{-\gamma}$$

$$\left(\frac{T_2}{T_1}\right)^{-\gamma} = \left(\frac{P_1}{P_2}\right)^{\gamma-1}$$

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma} = 300(8)^{(1.5-1)/1.5} = 300(8)^{1/3}$$

$T_2 = 600$ K $= (600 - 273)°C = 327°C$

6. (a) : Here,

$T_1 = 500$ K, As $\eta = 1 - \dfrac{T_2}{T_1}$ or $\dfrac{T_2}{T_1} = 1 - \eta$

$$\therefore \quad \frac{T_2}{500} = 1 - \frac{40}{100} = \frac{3}{5} \text{ or } T_2 = 300\ \text{K}$$

Now $\dfrac{T_2}{T_1'} = 1 - \eta' = 1 - \dfrac{50}{100} = \dfrac{1}{2}$

$$\therefore \quad T_1' = 2T_2 = 2\times300 = 600\ \text{K}$$

7. (c) : $dW = PdV = \dfrac{RT}{V}dV$ ...(i)

As $V = KT^{2/3}$ $\therefore$ $dV = K\dfrac{2}{3}T^{-1/3}\,dT$

$$\therefore \quad \frac{dV}{V} = \frac{K\frac{2}{3}T^{-1/3}dT}{KT^{2/3}} = \frac{2}{3}\frac{dT}{T}$$

From (i), $W = \displaystyle\int_{T_1}^{T_2} RT\,\frac{dV}{V} = \int_{T_1}^{T_2} RT\,\frac{2}{3}\frac{dT}{T}$

$$W = \frac{2}{3}R(T_2 - T_1) = \frac{2}{3}R\times60 = 40R$$

8. (d) : Efficiency of a Carnot engine,

$$\eta = 1 - \frac{T_2}{T_1} \quad \text{or} \quad \frac{T_2}{T_1} = 1 - \eta = 1 - \frac{40}{100} = \frac{3}{5}$$

$$\therefore \quad T_1 = \frac{5}{3}\times T_2 = \frac{5}{3}\times300 = 500\ \text{K}$$

Increase in efficiency = 50% of 40% = 20%

$\therefore$ New efficiency, $\eta' = 40\% + 20\% = 60\%$

$$\therefore \quad \frac{T_2}{T_1'} = 1 - \frac{60}{100} = \frac{2}{5}$$

$$\therefore \quad T_1' = \frac{5}{2}\times T_2 = \frac{5}{2}\times300 = 750\ \text{K}$$

Increase in temperature of source

$= T_1' - T_1 = 750 - 500 = 250$ K

9. (c) : Efficiency, $\eta = \dfrac{T_1 - T_2}{T_1} = \dfrac{W}{Q}$

$$W = \frac{Q(T_1 - T_2)}{T_1} = \frac{6\times10^4[(227+273)-(127+273)]}{(227+273)}$$

$$= \frac{6\times10^4\times100}{500} = 1.2\times10^4\ \text{cal}$$

10. (b) : Here, initial temperature,

$T_1 = 27°C = 273 + 27 = 300$ K

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Final temperature, $T_2 = 97°\ C = 273 + 97 = 370\ K$
When a gas is compressed adiabatically, work done on the gas is given by

$$W = \frac{R}{(1-\gamma)}(T_2 - T_1) = \frac{8.3 \times (370 - 300)}{1 - 1.5}$$

or $W = -11.62 \times 10^2\ J$
$\therefore$ Heat produced,

$$H = \frac{W}{J} = \frac{11.62 \times 10^2}{4.2} = 276.7\ cal$$

11. (b) : According to first Law of thermodynamic

$$\Delta Q = \Delta U + \Delta W$$

$$\therefore \quad \frac{\Delta Q}{\Delta t} = \frac{\Delta U}{\Delta t} + \frac{\Delta W}{\Delta t}$$

Here, $\frac{\Delta Q}{\Delta t} = 120\ W$,

$$\frac{\Delta W}{\Delta t} = 80\ J\ s^{-1}$$

$$\therefore \quad \frac{\Delta U}{\Delta t} = 120 - 80 = 40\ J\ s^{-1}$$

12. (b) : Work done by the gas during the isothermal process

$$W = nRT \ln \frac{V_2}{V_1}$$

$$= (1)RT \ln\left(\frac{2V}{V}\right) = RT \ln 2$$

13. (b) : Thermal capacity, S = Specific heat (s) × Mass (m)

$$\therefore \frac{S_A}{S_B} = \frac{m_A s_A}{m_B s_B} = \frac{\left(\frac{4}{3}\right)\pi r_A^3 \rho_A s_A}{\left(\frac{4}{3}\right)\pi r_B^3 \rho_B s_B}$$

$$= \left(\frac{r_A}{r_B}\right)^3 \frac{\rho_A s_A}{\rho_B s_B} = \left(\frac{1}{2}\right)^3 \times \left(\frac{2}{1}\right) \times \left(\frac{1}{3}\right) = \frac{1}{12}$$

14. (c) : As nitrogen is diatomic, its molar specific heat at constant pressure is

$$C_P = \frac{7}{2}R$$

No. of moles, $n = \frac{14}{28} = \frac{1}{2}$

$$\therefore \quad \Delta Q = nC_P \Delta T$$

$$= \frac{1}{2} \times \frac{7}{2} R \times 40 = 70R$$

15. (c) : As no work is done, therefore, $\Delta W = 0$
According to first law of thermodynamics

$$\Delta Q = \Delta U + \Delta W = \Delta U = nC_V \Delta T = n\left(\frac{R}{\gamma - 1}\right)\Delta T$$

Here, $n = 2, \gamma = \frac{5}{3}$

$$\Delta T = T_2 - T_1 = (373 - 273) = 100\ K$$

$$\Delta Q = 2 \times \frac{R}{\left(\frac{5}{3} - 1\right)} \times 100 = 300\,R$$

16. (c) : Heat supplied to a gas,
$\Delta Q = 1500\ J$
Work done by the gas,

$$\Delta W = P\Delta V = 2.1 \times 10^5 \times N\ m^{-2} \times 2.5 \times 10^{-3}\ m^3$$
$$= 5.25 \times 10^2\ N\ m = 525\ J$$

According to first law of thermodynamics,

$$\Delta Q = \Delta W + \Delta U$$
$$\Delta U = \Delta Q - \Delta W$$
$$= 1500\ J - 525\ J = 975\ J$$

17. (d) : The initial pressure and volume of gas are P and V.
Now the gas is compressed adiabatically to $1/4^{th}$ of its original volume, *i.e*

$$V_2 = \frac{V}{4} \qquad \ldots (i)$$

As $P_1 V_1^\gamma = P_2 V_2^\gamma \qquad \ldots (ii)$

or $PV^\gamma = P_2\left(\frac{V}{4}\right)^\gamma = \frac{P_2 V^\gamma}{4^\gamma}$ (using (i))

$$P_2 = 4^\gamma P$$

Now for monoatomic gases $\gamma = \frac{5}{3}$,

$$\therefore \quad P_2 = 4^{5/3} P = 10.08\ P$$

18. (a)

19. (c) : Here mass of oxygen (m) = 35 g,
molar mass of O_2 (M) = 32 g mol^{-1}
rise in temperature, $\Delta T = 80\ °C$

$$\therefore \quad \text{number of moles } n = \frac{m}{M} = \frac{35}{32} = 1.09\ mol$$

As oxygen is a diatomic gas, then molar specific heat at constant volume is $C_V = \frac{5}{2}R$

and amount of heat supplied to gas

$$\Delta Q = nC_V \Delta T$$

$$= 1.09 \times \frac{5}{2} R \times 80 = 1.09 \times \frac{5}{2} \times 8.3 \times 80$$

$$= 1809.4\ J = 1.8094\ kJ\ 1.81 \simeq 1.81\ kJ$$

20. (a) : Initially, $\eta = \frac{T_1 - T_2}{T_2}$

i.e. $0.5 = \frac{T_1 - (273 + 7)}{T_1}$ or $\frac{1}{2} = \frac{T_1 - 280}{T_1}$

$$\therefore \quad T_1 = 560\ K$$

Finally, $\eta_1' = \frac{T_1' - T_2}{T_1'}$ or $0.7 = \frac{T_1' - (273 + 7)}{T_1'}$

$$\therefore \quad T_1' = 933\ K$$

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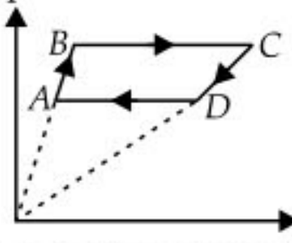
21. (a) : $\beta = \dfrac{Q_2}{W} = \dfrac{T_L}{T_H - T_L}$

$Q_2 = \dfrac{273}{303-273} = \dfrac{273}{30} \simeq 9$ J

Heat delivered to the surroundings

$Q_1 = Q_2 + W = 9 + 1 = 10$ J

22. (c) :



Processes A to B and C to D are parts of straight line graphs passing through origin $P \propto T$.

So, volume remains constant for the graph AB and CD

So, no work is done during processes for A to B and C to D

i.e., $W_{AB} = W_{CD} = 0$

and $W_{BC} = P_2(V_C - V_B) = nR(T_C - T_B)$

$= 6R(2200 - 800) = 6R \times 1400$ J

Also, $W_{DA} = P_1(V_A - V_D) = nR(T_A - T_D)$

$= 6R(600 - 1200) = -6R \times 600$ J

Hence, work done in complete cycle

$W = W_{AB} + W_{BC} + W_{CD} + W_{DA}$

$= 0 + 6R \times 1400 + 0 - 6R \times 600$

$= 6R \times 800 = 6 \times 8.3 \times 800 = 40$ kJ

23. (a) : For an isothermal process

PV = constant $\therefore$ $PV = P_I 2V$

$P_I = \dfrac{P}{2}$ ...(i)

For an adiabatic process

PV^γ = constant $\therefore$ $PV^\gamma = P_A(2V)^\gamma$

or $P_A = \dfrac{P}{2^\gamma}$ ...(ii)

Divide (i) by (ii), we get

$\dfrac{P_I}{P_A} = \dfrac{2^\gamma}{2} = 2^{\gamma - 1}$

24. (c)

25. (d) : Here $\eta_1 = \dfrac{1}{6}, \eta_2 = 2 \times \dfrac{1}{6}$

From, $\eta_1 = 1 - \dfrac{T_2}{T_1}$ or $\dfrac{1}{6} = 1 - \dfrac{T_2}{T_1}$ or $\dfrac{T_2}{T_1} = \dfrac{5}{6}$

or $T_2 = \dfrac{5}{6}T_1$ ...(i)

Again, $\eta_2 = 1 - \dfrac{(T_2 - 62)}{T_1}$ or $2 \times \dfrac{1}{6} = 1 - \dfrac{(T_2 - 62)}{T_1}$

$\dfrac{(T_2 - 62)}{T_1} = 1 - \dfrac{1}{3} = \dfrac{2}{3}$ or $3T_2 - 186 = 2T_1$

or $3 \times \dfrac{5}{6}T_1 - 186 = 2T_1$ (Using (i))

$0.5T_1 = 186$

$\therefore$ $T_1 = 372$ K

$T_1 = (372 - 273) = 99°C$

26. (c) : Here, $\gamma = \dfrac{7}{5}, P_1 = P, \rho_1 = \rho; P_2 = P', \rho_2 = \rho'$

For an adiabatic process, PV^γ = constant

$\therefore$ $P_1V_1^\gamma = P_2V_2^\gamma$

$\dfrac{P_2}{P_1} = \left(\dfrac{V_1}{V_2}\right)^\gamma = \left(\dfrac{\rho_2}{\rho_1}\right)^\gamma = \left(\dfrac{\rho'}{\rho}\right)^{7/5} = (32)^{7/5}$

$\dfrac{P'}{P} = (2^5)^{7/5} = 2^7 = 128$

27. (b) : As P–V diagram is a straight line passing through origin, therefore,

$P \propto V$ or PV^{-1} = constant

In the process, PV^x = constant, molar heat capacity is given by

$C = \dfrac{R}{\gamma - 1} + \dfrac{R}{1 - x}$

where $x = -1$ here and $\gamma = 1.4$ for diatomic gas.

$\therefore$ $C = \dfrac{R}{1.4 - 1} + \dfrac{R}{1 - (-1)} = \dfrac{5}{2}R + \dfrac{R}{2}$

$C = 3R$

28. (b) : Efficiency of Carnot engine,

$\eta = 1 - \dfrac{T_2}{T_1}$

where T_1 is the temperature of the source and T_2 is the temperature of the sink

For the 1st case

$\eta = 40\%$, $T_1 = 500$ K

$\therefore$ $\dfrac{40}{100} = 1 - \dfrac{T_2}{500}$

$\dfrac{T_2}{500} = 1 - \dfrac{40}{100} = \dfrac{3}{5}$

$T_2 = \dfrac{3}{5} \times 500 = 300$ K

For the 2nd case

$\eta = 60\%$, $T_2 = 300$ K

$\therefore$ $\dfrac{60}{100} = 1 - \dfrac{300}{T_1}$

$\dfrac{300}{T_1} = 1 - \dfrac{60}{100} = \dfrac{2}{5}$

$T_1 = \dfrac{5}{2} \times 300 = 750$ K

29. (c) : $\Delta Q = Q_1 + Q_2 + Q_3 + Q_4$

$= 5960$ J $- 5585$ J $- 2980$ J $+ 3645$ J $= 1040$ J

$\Delta W = W_1 + W_2 + W_3 + W_4$

$= 2200$ J $- 825$ J $- 1100$ J $+ W_4 = 275$ J $+ W_4$

For a cyclic process, $U_f = U_i$

$\Delta U = U_f - U_i = 0$

From first law of thermodynamics,

$\Delta Q = \Delta U + \Delta W$

1040 J $= 0 + 275$ J $+ W_4$ or $W_4 = 765$ J

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30. (c) : $W_{AB} = -P_0V_0$,

$W_{BC} = 0$

$W_{CD} = 4P_0V_0$

$W_{ABCD} = W_{AB} + W_{BC} + W_{CD}$

$= -P_0V_0 + 0 + 4P_0V_0 = 3P_0V_0$

31. (a) : Heat required by ice to convert totally into water at 100°C,

$Q_1 = 1 \times 80 + 1 \times 1 \times 100 = 180$ cal

Heat supplied by steam if it was to condense totally and convert into water at 100°C,

$Q_2 = 1 \times 540 = 540$ cal

As $Q_2 > Q_1$, entire steam will not condense and final temperature = 100°C.

Both water and steam will exist together in equilibrium at 100°C.

32. (c) : In cylinder A, heat is supplied at constant pressure while in cylinder B, heat is supplied at constant volume.

$\therefore (\Delta Q)_A = nC_P(\Delta T)_A$

and $(\Delta Q)_B = nC_V(\Delta T)_B$

Given: $(\Delta Q)_A = (\Delta Q)_B$

$$\therefore \quad (\Delta T)_B = \frac{C_P}{C_V}(\Delta T)_A = \gamma(\Delta T)_A \quad \left(\because \quad \gamma = \frac{C_P}{C_V}\right)$$

$$= \left(\frac{5}{3}\right)(42\text{ K}) = 70\text{ K}$$

33. (a) : Let T_1 be the temperature of diatomic gas at volume V and T_2 is the temperature at volume $32V$.

For an adiabatic process,

$TV^{\gamma-1} =$ constant

$\therefore \quad T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$

$$\text{or} \quad \frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = \left(\frac{V}{32V}\right)^{\gamma-1} = \frac{1}{(32)^{\gamma-1}}$$

For diatomic gas, $\gamma = \frac{7}{5}$

$$\therefore \quad \frac{T_2}{T_1} = \frac{1}{(32)^{\frac{7}{5}-1}} = \frac{1}{(2^5)^{\frac{7}{5}-1}} = \frac{1}{(2^5)^{2/5}} = \frac{1}{4} \qquad \ldots(i)$$

Efficiency of engine, $\eta = 1 - \frac{T_2}{T_1}$

$= 1 - \frac{1}{4}$ (Using (i))

$= \frac{3}{4} = 0.75$

34. (a) : Let L and A be length and area of cross-section of each rod.

At steady state,

$H_1 = H_2 + H_3$

$$\frac{(100 - T)(3K)A}{L} = \frac{(T - 50)2KA}{L} + \frac{(T - 0)KA}{L}$$

$3(100 - T) = 2(T - 50) + T$

$300 - 3T = 2T - 100 + T$

$6T = 400$

$$\text{or} \quad T = \frac{400}{6} = \frac{200}{3}\,^\circ\text{C}$$

35. (b) : Here, $\gamma = \frac{7}{5}$

$$\text{Work done} = \frac{nR}{\gamma - 1}\Delta T$$

$$= \frac{5 \times 8.3 \times 400}{\frac{7}{5} - 1} = 41500\text{ J} = 41.5 \times 10^3\text{ J} = 41.5\text{ kJ}$$

Work done = Change in internal energy

($\because \Delta Q = 0$ for adiabatic process)

$\therefore$ Change or increase in internal energy

= 41.5 kJ

36. (a) : Here, $V_1 = 5.6$ litre, $V_2 = 0.7$ litre, $W = ?$

Helium is a monoatomic gas.

For helium, $\gamma = \frac{5}{3}$

For an adiabatic process,

$TV\gamma^{-1} =$ constant

$$\therefore \quad T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1} \text{ or } T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$\text{or} \quad T_2 = T_1\left(\frac{5.6}{0.7}\right)^{\left(\frac{5}{3}-1\right)} = T_1(8)^{2/3} = 4T_1$$

$$\text{No. of moles of helium, } n = \frac{5.6\text{ litre}}{22.4\text{ litre}} = \frac{1}{4}$$

Work done during an adiabatic process is

$$W = \frac{nR[T_1 - T_2]}{(\gamma - 1)} = \frac{\frac{1}{4}R[T_1 - 4T_1]}{\left(\frac{5}{3} - 1\right)} = -\frac{9}{8}RT_1$$

Here –ve sign shows that work is done on the gas.

37. (a) : $\Delta t = \frac{1}{2}\alpha t\Delta T$

$= \frac{1}{2} \times 9 \times 10^{-7}\,^\circ\text{C}^{-1} \times 0.5\text{ s} \times (30^\circ\text{C} - 20^\circ\text{C})$

$= 22.5 \times 10^{-7}\text{ s} = 2.25 \times 10^{-6}\text{ s}$

38. (b) : $\Delta U = C_V\Delta T$.

Now

$$C_P - C_V = R \text{ or } \frac{C_P}{C_V} - 1 = \frac{R}{C_V}$$

$$\text{or} \quad C_V = \frac{R}{\gamma - 1}, \left(\because \quad \gamma = \frac{C_P}{C_V}\right).$$

$$\text{Hence} \quad \Delta U = \frac{R\Delta T}{(\gamma - 1)} = \frac{8.3 \times 8}{(1.4 - 1)} = 166\text{ J}$$

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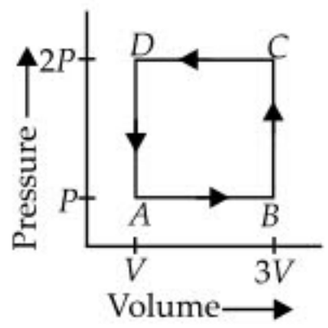
39. (a) : In a cyclic process, $\Delta U = 0$, and work done is equal to the area under the cycle and is positive if the cycle is clockwise and negative if anticlockwise.



$\therefore \Delta W$ = – Area of rectangle $ABCD$

$= -P(2V) = -2PV$

According to first law of thermodynamics

$\Delta Q = \Delta U + \Delta W$ or $\Delta Q = \Delta W$ (As $\Delta U = 0$)

i.e., heat supplied to the system is equal to the work done

So heat absorbed, $\Delta Q = \Delta W = -2PV$

$\therefore$ Heat rejected by the gas = $2PV$

40. (a) : For isothermal process : PV = constant

or $PV = P_1 \frac{V}{4} \Rightarrow P_1 = 4P$

For polytropic process: $PV^{1.5}$ = constant

$$PV^{1.5} = P_2\left(\frac{V}{4}\right)^{1.5}$$

$$\Rightarrow P_2 = (2^2)^{3/2} P = 8P$$

$$\therefore \frac{P_1}{P_2} = \frac{1}{2}$$

41. (b) : For an isothermal process, PV = constant

or $P \propto \frac{1}{V}$

42. (a) : In a process PV^x = constant, molar heat capacity is given by $C = \frac{R}{\gamma - 1} + \frac{R}{1 - x}$

As the process is $\frac{P}{V}$ = constant,

i.e., PV^{-1} = constant, therefore, $x = -1$.

For an ideal monoatomic gas, $\gamma = \frac{5}{3}$

$$\therefore C = \frac{R}{\frac{5}{3} - 1} + \frac{R}{1 - (-1)} = \frac{3}{2}R + \frac{R}{2} = 2R$$

$\Delta Q = nC(\Delta T) = 1(2R)(2T_0 - T_0) = 2RT_0$

43. (c) : According to ideal gas equation, $PV = nRT$

When pressure is constant, $PdV = nRdT$

$P(2V - V) = nRdT$

$PV = nRdT$ ...(i)

As $\gamma = \frac{C_P}{C_V}$

$$\therefore \gamma - 1 = \frac{C_P - C_V}{C_V}$$

or $C_V = \frac{C_P - C_V}{\gamma - 1} = \frac{R}{\gamma - 1}$ ($\because C_P - C_V = R$)

$$\Delta U = nC_V dT = \frac{nRdT}{\gamma - 1}$$

$$\Delta U = \frac{PV}{\gamma - 1}$$ (Using (i))

44. (a) : Efficiency of Carnot's heat engine,

$$\eta = 1 - \frac{T_2}{T_1}$$

For first Carnot's heat engine, $0.5 = 1 - \frac{T_2}{T_1}$

For second heat engine, $0.5 = 1 - \frac{T_2'}{T_1'}$

Efficiency remains the same when both T_1 and T_2 are increased by same factor

Therefore, the temperature of source and sink of second engine are

$T_1' = 2T_1$, $T_2' = 2T_2$

45. (d)

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Kinetic Theory

Kinetic theory of gases

The kinetic theory of gases correlates the macroscopic properties of gases e.g., pressure, temperature etc. to the microscopic properties of gas molecules e.g. speed, momentum, kinetic energy of molecules etc. The kinetic theory of gases is based on the following assumptions :

- A gas consists of a very large number of molecules which are perfect elastic spheres. They are identical in all respects for a given gas and are different for different gases.
- The molecules of a gas are moving in all directions with different speeds.
- The size of the gas molecules is very small as compared to the distance between them. Hence volume occupied by the molecules is negligible in comparison to the volume of the gas.
- The molecules do not exert any force of attraction or repulsion on each other, except during collision.
- The collisions of the molecules with themselves and with the walls of the vessel are perfectly elastic.
- A molecule moves along a straight line between two successive collisions and the average straight distance covered between two successive collisions is called the mean free path of the molecules.
- The collision are almost instantaneous *i.e.* the time of collision of two molecules is negligible as compared to time interval between two successive collisions.

Ideal gas

An ideal gas or a perfect gas is that gas which strictly obeys the gas laws.

Following are the characteristics of the ideal gas :

- The size of the molecule of a gas is zero, *i.e.*, each molecule of a gas is a point mass with no dimensions.
- There is no force of attraction or repulsion amongst the molecules of the gas.

Equation of an ideal gas

$PV = \mu RT = k_B NT$

where μ is the number of moles and N is the number of molecules, R is the universal gas constant and k_B is the **Boltzmann constant.**

$$k_B = \frac{R}{N_A}$$

N_A is the **Avogadro's number.**

Here, $\mu = \frac{m}{M} = \frac{N}{N_A}$

where m is the mass of the gas containing N molecules, M is the molar mass.

Another form of an ideal gas equation $P = \frac{\rho RT}{M}$

where ρ is the density of the gas.

Gas laws

Boyle's law

According to this law, at constant temperature, the volume of a given mass of a gas is inversely proportional to the pressure.

$$V \propto \frac{1}{P} \quad \text{or} \quad PV = \text{constant.}$$

Charles's law

According to this law, at constant pressure, volume of a given mass of gas is directly proportional to its absolute temperature.

$$V \propto T \quad \text{or} \quad \frac{V}{T} = \text{constant.}$$

Gay Lussac's law or Regnault's law

According to this law, at constant volume, pressure of the given mass of a gas is directly proportional to its absolute temperature.

$$P \propto T \quad \text{or} \quad \frac{P}{T} = \text{constant.}$$

Avogadro's law

According to this law, at same temperature and pressure, equal volumes of all the gases contain equal number of molecules.

$N_1 = N_2$, if P, V and T are the same.

Graham's law of diffusion

According to this law, at constant pressure and temperature, the rate of diffusion of a gas is inversely proportional to the square root of its density.

$$\text{Rate of diffusion} \propto \frac{1}{\sqrt{\rho}}, \text{ if } P \text{ and } T = \text{constant.}$$

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Dalton's law of partial pressure

According to this law, total pressure exerted by a mixture of non-reactive ideal gases is equal to sum of the partial pressure which each would exert, if it alone occupied the same volume at the given temperature.

$$P = P_1 + P_2 + P_3 + ...$$

Kinetic theory of an ideal gas

According to kinetic theory of an ideal gas pressure exerted by an ideal gas is given by

$$P = \frac{1}{3} mn \overline{v^2}$$

where n is the number density (number of molecules per unit volume), m is the mass of molecule and $\overline{v^2}$ is the mean square speed.

Kinetic Interpretation of Temperature

Average kinetic energy per molecule of a gas is

$$E = \frac{1}{2} m\overline{v^2} = \frac{3}{2} k_B T$$

Average kinetic energy per molecule of a gas depends only on its absolute temperature. It is independent of pressure, volume and nature of the ideal gas.

At a given temperature, the average kinetic energy per molecule of all the gases is same.

Average kinetic energy per mole of a gas is

$$E = \frac{3}{2} RT$$

Relation between pressure and kinetic energy of gas

$$PV = \frac{2}{3} E$$

Absolute zero of temperature : Absolute zero of temperature may be defined as that temperature at which the velocities of the gas molecules become zero. In other words, all molecular motion ceases at absolute zero of temperature. The value of absolute zero for an ideal gas is −273°C. This definition is true only in the case of an ideal gas.

Different type of Speed of Gas Molecules

Root mean square speed

$$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{m}}$$

Average speed

$$\overline{v} = \sqrt{\frac{8RT}{\pi M}} = \sqrt{\frac{8k_B T}{\pi m}}$$

Most probable speed

$$v_{mp} = \sqrt{\frac{2RT}{M}} = \sqrt{\frac{2k_B T}{m}}$$

$$v_{rms} > \overline{v} > v_{mp}$$

Degree of freedom

The number of degrees of freedom of a gas molecule is given by

$$f = 3N - K$$

where

N = Number of atoms in the molecule

K = Number of independent relations between atoms of a molecule

The value of degree of freedom for different type of gas molecules is as shown in the table.

Type of molecule	Arrangement of atoms	N	K	f
Monoatomic		1	0	3
Diatomic		2	1	5
Triatomic (non linear)		3	3	6
Triatomic (linear)		3	2	7

Law of equipartition of energy

It states that if a system is in equilibrium at absolute temperature, T, the total energy is distributed equally in different energy modes of absorption, the energy in each mode being equal to (1/2) $k_B T$. Each translational and rotational degree of freedom corresponding to one energy mode of absorption and has energy $(1/2)k_B T$. Each vibrational frequency has two modes of energy (kinetic and potential) with corresponding energy equal to

$$2 \times \frac{1}{2} k_B T = k_B T.$$

Specific heat capacity

Monatomic Gases

The molecule of a monatomic gas has only three translational degrees of freedom.

The total internal energy of a mole of such a gas is given by

$$U = \frac{3}{2} k_B T \times N_A = \frac{3}{2} RT$$

The molar specific heat at constant volume, C_V is

$$C_V = \frac{dU}{dT} = \frac{3}{2} R$$

The molar specific heat at constant pressure, C_P is

$$C_P = \frac{5}{2} R$$

Ratio of specific heats, $\gamma = \frac{C_P}{C_V} = \frac{5}{3}$

Diatomic Gases

A diatomic gas molecule treated as a rigid rotator like a dumbbell has 5 degrees of freedom: 3 translational and 2 rotational.

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The total internal energy of a mole of such a gas is given by

$$U = \frac{5}{2}k_B T \times N_A = \frac{5}{2}RT$$

The molar specific heats are given by

$$C_V \text{ (rigid diatomic)} = \frac{5}{2}R$$

$$C_P \text{ (rigid diatomic)} = \frac{7}{2}R$$

$$\gamma \text{ (rigid diatomic)} = \frac{7}{5}$$

If the diatomic molecule is not rigid but has in addition a vibrational mode, then

$$U = \left(\frac{5}{2}k_B T + k_B T\right)N_A = \frac{7}{2}RT$$

$$C_V = \frac{7}{2}R,\ C_P = \frac{9}{2}R,\ \ \gamma = \frac{9}{7}$$

Polyatomic Gases

In general, a polyatomic gas molecule has 3 translational, 3 rotational degrees of freedom and a certain number (f) of vibrational mode. The total internal energy of a mole of such a gas is given by

$$U = \left(\frac{3}{2}k_B T + \frac{3}{2}k_B T + f\,k_B T\right)N_A = (3+f)RT$$

The molar specific heats are given by

$$C_V = (3+f)R,$$
$$C_P = (4+f)R$$
$$\gamma = \frac{(4+f)}{(3+f)}$$

Note : $C_P - C_V = R$.

This relation is known as **Mayer's relation.** It is true for any ideal gas whether monatomic, di or polyatomic.

Relation between γ and degree of freedom (f)

$$\gamma = 1 + \frac{2}{f}$$

Mean free path

It is the average distance covered by a molecule between two successive collisions and is given by

$$\lambda = \frac{1}{\sqrt{2}n\pi d^2}$$

where n is the number density and d the diameter of the molecule.

Mean free path related to the temperature (T) and pressure (P) as

$$\lambda = \frac{k_B T}{\sqrt{2}\pi d^2 P}$$

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EXAM DRILL

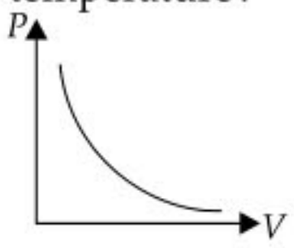
1. A gaseous mixture consists of 16 g of helium and 16 g of oxygen. The ratio C_P/C_V of the mixture is
(a) 1.4 (b) 1.54 (c) 1.59 (d) 1.62

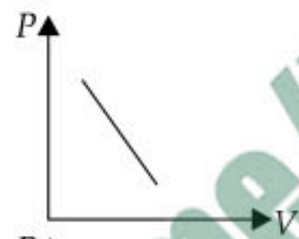
2. The velocity of sound in hydrogen is 1224 m s^{-1}. Its velocity in mixture of hydrogen and oxygen containing 4 parts by volume of hydrogen and 1 part oxygen is
(a) 1224 m s^{-1} (b) 612 m s^{-1}
(c) 2448 m s^{-1} (d) 306 m s^{-1}

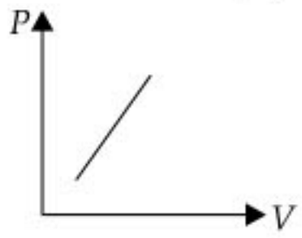
3. One kg of a diatomic gas is at a pressure of 8×10^4 N m^{-2}. The density of the gas is 4 kg m^{-3}. What is the energy of the gas due to its thermal motion?
(a) 3×10^4 J (b) 5×10^4 J
(c) 6×10^4 J (d) 7×10^4 J

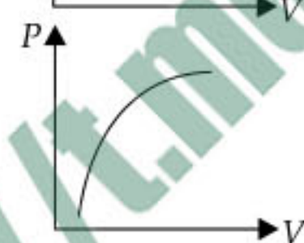
4. Heat is supplied to a diatomic gas at constant pressure. The ratio of $\Delta Q : \Delta U : \Delta W$ is
(a) 5 : 3 : 2 (b) 7 : 5 : 2 (c) 2 : 3 : 5 (d) 2 : 5 : 7

5. Which of the following graph best represents the variation of pressure (P) with volume (V) of a gas at a fixed temperature?

(a) 

(b) 

(c) 

(d) 

6. Suppose ideal gas equation follows VP^3 = constant. Initial temperature and volume of gas are T and V respectively. If gas expands to $27V$, then its temperature will become
(a) T (b) $9T$ (c) $27T$ (d) $\frac{T}{9}$

7. The ratio of root mean square velocities of O_3 and O_2 is
(a) 1 : 1 (b) 2 : 3 (c) 3 : 2 (d) $\sqrt{2} : \sqrt{3}$

8. Two moles of monoatomic gas is mixed with three moles of a diatomic gas. The molar specific heat of the mixture at constant volume is
(a) $1.55R$ (b) $2.10R$ (c) $1.63R$ (d) $2.20R$

9. The mass of oxygen gas occupying a volume of 11.2 litres at a temperature 27°C and a pressure of 1 atm in kilograms is
(Molecular weight of oxygen = 32)
(a) 0.001456 (b) 0.01456
(c) 0.1456 (d) 1.1456

10. A gas at one atmosphere and 100 mL is mixed with another gas of equal moles at 0.5 atm and having volume 50 mL in flask of 1 L. What is their final pressure?
(a) 0.5 atm (b) 1 atm
(c) 0.75 atm (d) 0.125 atm

11. The value of $\frac{PV}{T}$ for one mole of an ideal gas is nearly equal to
(a) 2 J mol^{-1} K^{-1} (b) 8.3 J mol^{-1} K^{-1}
(c) 4.2 J mol^{-1} K^{-1} (d) 2 cal mol^{-1} K^{-1}

12. At NTP, the ratio of molecules in 1 cc of oxygen to that in 1 cc of hydrogen is
(a) 1 : 1 (b) 1 : 4 (c) 1 : 16 (d) 1 : 2

13. The ideal gas equation connecting pressure (P), volume (V) and absolute temperature (T) is
(a) $PV = \frac{k_B N}{T}$ (b) $P = \frac{k_B N}{VT}$
(c) $PV = k_B NT$ (d) $P = \frac{k_B NV}{T}$
where k_B is the Boltzmann constant and N is the number of molecules.

14. Mean free path of a gas molecule is
(a) inversely proportional to number of molecules per unit volume
(b) inversely proportional to diameter of the molecule
(c) directly proportional to the square root of the absolute temperature
(d) directly proportional to the molecular mass

15. If for a gas $\frac{R}{C_V} = 0.67$, this gas is made up of molecules which are
(a) monoatomic (b) diatomic
(c) polyatomic
(d) mixture of diatomic and polyatomic molecules

16. A diatomic gas is heated at constant pressure. What fraction of the heat energy is used to increase the internal energy?
(a) $\frac{3}{5}$ (b) $\frac{3}{7}$ (c) $\frac{5}{7}$ (d) $\frac{5}{9}$

17. If one mole of a monoatomic gas $\left(\gamma = \frac{5}{3}\right)$ is mixed with one mole of a diatomic gas $\left(\gamma = \frac{7}{5}\right)$, the value of γ for the mixture is
(a) 1.40 (b) 1.50 (c) 1.53 (d) 3.07

18. At room temperature, the rms speed of the molecules of a certain diatomic gas is found to be 1933 m s^{-1}. The gas is (R = 8.3 J mol^{-1} K^{-1})
(a) H_2 (b) F_2 (c) Cl_2 (d) O_2

19. The root mean square velocity of hydrogen molecules at 300 K is 1930 m s^{-1}. The rms velocity of oxygen molecules at 1200 K will be

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(a) 965 m s^{-1} (b) 765 m s^{-1}
(c) 1065 m s^{-1} (d) 865 m s^{-1}

20. One litre of oxygen at a pressure of 1 atm and two litres of nitrogen at a pressure of 0.5 atm are introduced into a vessel of volume 1 litre. If there is no change in temperature, the final pressure of the mixture of gas (in atm) is
(a) 1.5 (b) 2.5 (c) 2 (d) 4

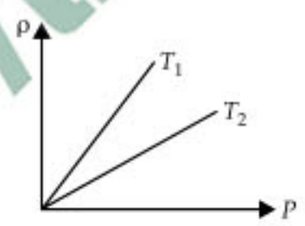
21. The average kinetic energy of the molecules of a low density gas at 27°C is
(Boltzmann constant = 1.38×10^{-23} J K^{-1})
(a) 3.1×10^{-20} J (b) 3.5×10^{-21} J
(c) 5.3×10^{-18} J (d) 6.21×10^{-21} J

22. If C_P and C_V denote the specific heats of nitrogen per unit mass at constant pressure and constant volume respectively, then
(a) $C_P - C_V = 28R$ (b) $C_P - C_V = R/28$
(c) $C_P - C_V = R/14$ (d) $C_P - C_V = R$

23. The molar specific heat at constant pressure of an ideal gas is $\left(\frac{7}{2}R\right)$. The ratio of specific heat at constant pressure to that at constant volume is
(a) 9/7 (b) 7/5 (c) 5/7 (d) 8/7

24. At what temperature does the mean kinetic energy of hydrogen molecules increase to such an extent that they escape out of the gravitational field of earth for ever?
(1 a.m.u. = 1.66×10^{-27} kg, escape velocity of earth = 11.2 km s^{-1}, Boltzmann constant = 1.38×10^{-23} J K^{-1})
(a) 9059 K (b) 10059 K
(c) 12059 K (d) 12075 K

25. The figure shows density (ρ) versus pressure (P) for an ideal gas at two absolute temperatures T_1 and T_2. Then,



(a) $T_1 > T_2$ (b) $T_1 < T_2$
(c) $T_1 = T_2$ (d) can't say

26. Two balloons are filled, one with pure He gas and other by air, respectively. If the pressure and temperature of these balloons are same, then the number of molecules per unit volume is
(a) more in the He filled balloon
(b) same in both balloons
(c) more in air filled balloon
(d) in the ratio of 1 : 4

27. A vessel of volume 4 litres contains a mixture of 8 g of oxygen, 14 g of nitrogen and 22 g of carbon dioxide at 27°C. The pressure exerted by the mixture is
(a) 5.79×10^5 N m^{-2} (b) 6.79×10^5 N m^{-2}
(c) 9.34×10^9 N m^{-2} (d) 9.34×10^5 N m^{-2}

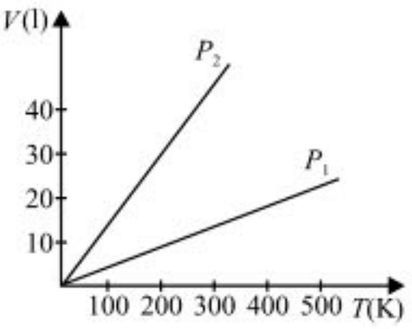
28. The root mean square velocity of the molecules of a gas is 1260 m s^{-1}. The average speed of the molecules is
(a) 1029 m s^{-1} (b) 1161 m s^{-1}
(c) 1671 m s^{-1} (d) 917 m s^{-1}

29. At 10°C, the value of the density of a fixed mass of an ideal gas divided by its pressure is x. At 110°C, this ratio is
(a) x (b) $\frac{383}{283}x$ (c) $\frac{10}{110}x$ (d) $\frac{283}{383}x$

30. The average energy for molecules in one degree of freedom is
(a) $\frac{3}{2}kT$ (b) $\frac{kT}{2}$ (c) $\frac{3}{4}kT$ (d) kT

31. 0.014 kg of nitrogen is enclosed in a vessel at a temperature of 27 °C. How much heat has to be transferred to the gas to double the rms velocity of its molecules?
(a) 1200 K (b) 600 K (c) 300 K (d) 150 K

32. Volume versus temperature graphs for a given mass of an ideal gas are shown in figure at two different values of constant pressure. What can be inferred about relation between P_1 and P_2?



(a) $P_1 > P_2$ (b) $P_1 = P_2$
(c) $P_1 < P_2$ (d) data is insufficient

33. A real gas behaves like an ideal gas if its
(a) both pressure and temperature are high
(b) both pressure and temperature are low
(c) pressure is high and temperature is low
(d) pressure is low and temperature is high

34. Pressure of a gas at constant volume is proportional to
(a) total internal energy of the gas
(b) average kinetic energy of the molecules
(c) average potential energy of the molecules
(d) total energy of the gas

35. Three moles of oxygen are mixed with two moles of helium. What will be the ratio of specific heats at constant pressure and constant volume for the mixture?
(a) 2.5 (b) 3.5 (c) 1.5 (d) 1

36. A vessel contains two non-reactive gases neon (monoatomic) and oxygen (diatomic). The ratio of their partial pressures is 3 : 2. The ratio of number of molecules is
(a) $\frac{3}{2}$ (b) $\frac{2}{3}$ (c) $\frac{1}{3}$ (d) $\frac{1}{2}$

37. A vessel is filled with a gas at a pressure of 76 cm of mercury of a certain temperature. The mass of the gas is increased by 50% by introducing more gas in the vessel at the same temperature. The resultant pressure of the gas is
(a) 76 cm of mercury (b) 108 cm of mercury
(c) 112 cm of mercury (d) 114 cm of mercury

38. Two moles of a gas A at 27 °C mixed with a 3 moles of gas at 37 °C. If both are monoatomic ideal gases, what will be the temperature of the mixture?
(a) 66 °C (b) 11 °C (c) 22 °C (d) 33 °C

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39. When the temperature of a gas filled in a closed vessel is increased by 1 °C, its pressure increases by 0.4 percent. The initial temperature of gas was
(a) 250 °C (b) 25 °C (c) 250 K (d) 25 K

40. 1/2 mole of helium is contained in a container at STP. How much heat energy is needed to double the pressure of the gas, (volume is constant) heat capacity of gas is 3 J g^{-1} K^{-1}.
(a) 1436 J (b) 736 J (c) 1638 J (d) 5698 J

41. One mole of an ideal monoatomic gas at temperature T_0 expands slowly according to the law $\frac{P}{V}$ = constant. If the final temperature is $2T_0$, heat supplied to the gas is
(a) $2RT_0$ (b) RT_0 (c) $\frac{3}{2}RT_0$ (d) $\frac{1}{2}RT_0$

42. The pressure and density of a diatomic gas $\left(\gamma = \frac{7}{5}\right)$ changes adiabatically from (P, d) to (P', d'). If $\frac{d'}{d} = 32$ then $\frac{P'}{P}$ is
(a) $\frac{1}{128}$ (b) 32 (c) 128 (d) 256

43. A balloon contains 1500 m^3 of helium at 27 °C and 4 atmospheric pressure. The volume of helium at –3 °C and 2 atmospheric pressure will be
(a) 1500 m^3 (b) 1700 m^3
(c) 1900 m^3 (d) 2700 m^3

44. The average translational kinetic energy of O_2 at a particular temperature 0.768 eV. The average translational kinetic energy of N_2 molecules in eV at the same temperature is
(a) 0.0015 (b) 0.0030 (c) 0.048 (d) 0.768

45. When an ideal gas is compressed adiabatically, its temperature rises the molecules on the average have more kinetic energy than before. The kinetic energy increases
(a) because of collisions with moving parts of the wall only.
(b) because of collisions with the entire wall.
(c) because the molecules gets accelerated in their motion inside the volume.
(d) because the redistribution of energy amongst the molecules.

DAY 12 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____
(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (d) : For 16 g of helium, $\mu_1 = \frac{16}{4} = 4$

For 16 g of oxygen, $\mu_2 = \frac{16}{32} = \frac{1}{2}$

For mixture of gases,

$$C_V = \frac{\mu_1 C_{V_1} + \mu_2 C_{V_2}}{\mu_1 + \mu_2} \quad \text{where } C_V = \frac{f}{2}R$$

$$C_P = \frac{\mu_1 C_{P_1} + \mu_2 C_{P_2}}{\mu_1 + \mu_2} \quad \text{where } C_P = \left(\frac{f}{2} + 1\right)R$$

For helium, $f = 3$, $\mu_1 = 4$

For oxygen, $f = 5$, $\mu_2 = \frac{1}{2}$

$$\therefore \quad \frac{C_P}{C_V} = \frac{\left(4 \times \frac{5}{2}R\right) + \left(\frac{1}{2} \times \frac{7}{2}R\right)}{\left(4 \times \frac{3}{2}R\right) + \left(\frac{1}{2} \times \frac{5}{2}R\right)} = \frac{47}{29} = 1.62.$$

2. (b) : If $\rho_H = 1$, then $\rho_{mix} = \frac{4 \times 1 + 1 \times 16}{(4+1)} = 4$

$$\frac{v_{mix}}{v_H} = \sqrt{\frac{\rho_H}{\rho_{mix}}} = \sqrt{\frac{1}{4}} = \frac{1}{2}$$

$$v_{mix} = \frac{v_H}{2} = \frac{1224}{2} = 612 \text{ m s}^{-1}$$

3. (b) : The thermal energy or internal energy is

$U = \frac{5}{2}\mu RT$ for diatomic gases. (5 is the degrees of freedom as the gas is diatomic)

But $PV = \mu RT$

$$V = \frac{\text{Mass}}{\text{Density}} = \frac{1 \text{ kg}}{4 \text{ kg m}^{-3}} = \frac{1}{4} \text{ m}^3$$

$P = 8 \times 10^4 \text{ N m}^{-2}$ (Given)

$$\therefore \quad U = \frac{5}{2} \times 8 \times 10^4 \times \frac{1}{4} = 5 \times 10^4 \text{ J}$$

4. (b) : For a diatomic gas, $C_V = \frac{5}{2}R$, $C_P = \frac{7}{2}R$

$$\Delta Q = nC_P \Delta T = n\left(\frac{7}{2}R\right)\Delta T$$

$$\Delta U = nC_V \Delta T = n\left(\frac{5}{2}R\right)\Delta T$$

$$\Delta W = \Delta Q - \Delta U = nR\Delta T$$

$$\therefore \Delta Q : \Delta U : \Delta W = \frac{7}{2} : \frac{5}{2} : 1 \text{ or } 7 : 5 : 2$$

5. (a) : The relation of P and V when temperature is constant is given by Boyle's law as PV = a constant. The variation of P and V will be a curve as shown in figure (a).

6. (b) : Given: $VP^3 = \text{constant} = k$ or $P = \frac{k}{V^{1/3}}$

According to ideal gas equation,

$PV = nRT$

$$\therefore \quad \frac{k}{V^{1/3}}V = nRT \quad \text{or} \quad V^{2/3} = \frac{nRT}{k}$$

Hence, $\left(\frac{V_1}{V_2}\right)^{2/3} = \frac{T_1}{T_2}$

$$\left[\frac{V}{27V}\right]^{2/3} = \frac{T_1}{T_2} \text{ or } T_2 = 9\,T_1 = 9T$$

7. (d) : $v_{rms} = \sqrt{\frac{3RT}{M}}$

or $v_{rms} \propto \frac{1}{\sqrt{M}}$ (At a given temperature T)

$$\therefore \quad \frac{(v_{rms})_{O_3}}{(v_{rms})_{O_2}} = \sqrt{\frac{M_{O_2}}{M_{O_3}}} = \sqrt{\frac{32}{48}} = \sqrt{\frac{2}{3}}$$

8. (b) : Molar specific heat of the mixture at constant volume is

$$(C_V)_{mixture} = \frac{n_1 C_{V_1} + n_2 C_{V_1}}{(n_1 + n_2)}$$

$$= \frac{2\left(\frac{3}{2}R\right) + 3\left(\frac{5}{2}R\right)}{2+3} = 2.1R$$

9. (b) : Here, $P = 1$ atm, $V = 11.2$ litres, $T = 27°\text{C} = 300$ K

$R = 0.0821$ L atm mol^{-1} K^{-1}

As $PV = \frac{m}{M}\text{RT}$

$$\therefore \quad m = \frac{PVM}{RT} = \frac{1 \times 11.2 \times 32}{0.0821 \times 300} = 14.56 \text{ g} = 0.01456 \text{ kg}$$

10. (d) : No. of moles in mixture is the sum of separate no. of moles of gases.

$n = n_1 + n_2$

or $\frac{PV}{RT} = \frac{P_1V_1}{RT} + \frac{P_2V_2}{RT}$ or $P \times 1000 = 1 \times 100 + 0.5 \times 50$

or $P = \frac{125}{1000}\text{atm} = 0.125 \text{ atm}$

11. (d) : The value of $\frac{PV}{T}$ for one mole of an ideal gas = gas constant = 2 cal mol^{-1} K^{-1}

12. (a)

13. (c) : According to ideal gas equation, $PV = Nk_BT$

14. (a) : Mean free path, $\lambda = \frac{1}{\sqrt{2}\pi d^2 n}$

where, n = Number of molecules per unit volume

d = Diameter of the molecule

As $PV = k_BNT$

$$n = \frac{N}{V} = \frac{P}{k_BT} \quad \therefore \quad \lambda = \frac{k_BT}{\sqrt{2}\pi d^2 P}$$

where,

k_B = Boltzmann constant

P = Pressure of gas

T = Absolute temperature of the gas

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15. (a) : For a gas, we know $\frac{R}{C_V} = \gamma - 1$

or, $0.67 = \gamma - 1$ or, $\gamma = 1.67$

Hence the gas is monoatomic.

16. (c) : Fraction of supplied energy which increases the internal energy is given by

$$f = \frac{\Delta U}{(\Delta Q_P)} = \frac{(\Delta Q)_V}{(\Delta Q_P)_P} = \frac{\mu C_V \Delta T}{\mu C_P \Delta T} = \frac{1}{\gamma} \left(\because \ \frac{C_V}{C_P} = \frac{1}{\gamma} \right)$$

For diatomic gas, $\gamma = \frac{7}{5} \Rightarrow f = \frac{5}{7}$

17. (b) : $\gamma_{\text{mixture}} = \dfrac{\frac{n_1\gamma_1}{\gamma_1 - 1} + \frac{n_2\gamma_2}{\gamma_2 - 1}}{\frac{n_1}{\gamma_1 - 1} + \frac{n_2}{\gamma_2 - 1}}$

Here, $n_1 = 1,\ \gamma_1 = \frac{5}{3},\ n_2 = 1,\ \gamma_2 = \frac{7}{5}$

$$\therefore \quad \gamma_{\text{mixture}} = \frac{\frac{1 \times \frac{5}{3}}{\left[\frac{5}{3} - 1\right]} + \frac{1 \times \frac{7}{5}}{\left[\frac{7}{5} - 1\right]}}{\left[\frac{1}{\frac{5}{3} - 1}\right] + \left[\frac{1}{\frac{7}{5} - 1}\right]} = \frac{3}{2} = 1.5$$

18. (a) : The velocity of gas at temperature T is given by

$$v_{\text{rms}} = \sqrt{\frac{3RT}{M}}$$

where, R is gas constant and M the molecular weight.

Given, $R = 8.3\text{J mol}^{-1}\text{ K}^{-1}$

$T = 27°\text{C} = 27 + 273 = 300\text{ K}$

$v^2_{\text{rms}} = 1933\text{ m s}^{-1}$

$$\therefore \quad M = \frac{3RT}{v^2_{\text{rms}}} = \frac{3 \times 8.3 \times 300}{(1933)^2} \ \therefore \ M \approx 2 \times 10^{-3}\text{ kg}$$

which is molecular weight of H_2.

19. (a) : $v_{\text{rms}} \propto \sqrt{T/M}$

$$\therefore \quad (v_O)_{\text{rms}} = \sqrt{\frac{T_O / M_O}{T_H / M_H}} = \sqrt{\frac{T_O}{T_H} \times \frac{M_H}{M_O}}$$

$$(v_H)_{\text{rms}} = \sqrt{\frac{1200}{300} \times \frac{2}{32}} = \frac{1}{2}$$

$$\therefore \quad (v_O)_{\text{rms}} = \frac{1}{2} v_H = \frac{1}{2} \times 1930 = 965\text{ m s}^{-1}$$

20. (c) : For oxygen, $P_1V_1 = P_2V_2$

or $1 \times 1 = P_2 \times 1$ or $P_2 = 1$ atm.

For nitrogen, $P_1'V_1' = P_2'V_2'$

or $0.5 \times 2 = P_2' \times 1$ or $P_2' = 1$ atm

$\therefore \quad P = P_2 + P_2' = 1 + 1 = 2$ atm

21. (d) : Kinetic energy $= \frac{3}{2}kT = \frac{3}{2} \times (1.38 \times 10^{-23})(300)$

$= 6.21 \times 10^{-21}$ J

22. (b) : Molar heat capacity = Molar mass × specific heat capacity

So, the molar heat capacities at constant pressure and constant volume will be $28C_P$ and $28C_V$ respectively.

$$\therefore \quad 28C_P - 28C_V = R \quad \text{or} \quad C_P - C_V = \frac{R}{28}$$

23. (b) : Here, $C_P = \frac{7}{2}R;\ C_V = C_P - R = \frac{7}{2}R - R = \frac{5}{2}R$

$$\gamma = \frac{C_P}{C_V} = \frac{7R/2}{5R/2} = \frac{7}{5}$$

24. (b) : $\frac{1}{2}mv_e^2 = \frac{3}{2}kT$

$$\therefore \quad T = \frac{m(v_e)^2}{3k} = \frac{(2 \times 1.66 \times 10^{-27}) \times (11.2 \times 10^3)^2}{3 \times (1.38 \times 10^{-23})} = 10059\text{ K}$$

25. (b) : As $PV = nRT$ or $\frac{Pm}{\rho} = nRT \ \left(\because \ V = \frac{m}{\rho} \right)$

$$\therefore \quad \rho = \frac{m}{nRT} P$$

This shows that $\rho \propto P$ so the graph of ρ and P is a Straight line with slope $\left(\frac{m}{nRT} \right)$.

Here the slope of graph $\propto \frac{1}{T}$

Hence $T_2 > T_1$.

26. (b) : Assuming the balloons have the same volume, as $PV = nRT$, if P, V and T are the same, n, the number of moles present will be the same, whether it is He or air. Hence, number of molecules per unit volume will be same in both the balloons.

27. (d) : The pressure exerted by the mixture,

$P = P_1 + P_2 + P_3$

$$= \left(\frac{nRT}{V} \right)_{O_2} + \left(\frac{nRT}{V} \right)_{N_2} + \left(\frac{nRT}{V} \right)_{CO_2}$$

$$= (n_{O_2} + n_{N_2} + n_{CO_2}) \frac{RT}{V} = \frac{\left(\frac{8}{16} + \frac{14}{28} + \frac{22}{44} \right)(8.31) \times 300}{4 \times 10^{-3}}$$

$= 9.34 \times 10^5\text{ N m}^{-2}$

28. (b) : $v_{\text{av}} = \sqrt{\frac{8kT}{m\pi}}, v_{\text{rms}} = \sqrt{\frac{3kT}{m}}$

$$\therefore \quad \frac{v_{\text{av}}}{v_{\text{rms}}} = \frac{\sqrt{8/\pi}}{\sqrt{3}} \quad \text{or} \quad \frac{v_{\text{av}}}{1260} = \sqrt{\frac{8}{3\pi}}$$

$$\therefore \quad v_{\text{av}} = 1260 \times \sqrt{\frac{8}{3\pi}} = 1161\text{ m s}^{-1}$$

29. (d) : For a given mass m of an ideal gas of gas constant R and density ρ,

$$\frac{PV}{T} = R \ \text{ or } \ \frac{Pm}{\rho T} = R \ \text{ or } \ \frac{\rho}{P} = \frac{m}{TR}$$

or $x = \frac{m}{TR}$ or $xT = \frac{m}{R}$ = a constant

$\therefore \quad x_1T_1 = x_2T_2$

or $x_2 = x_1 \frac{T_1}{T_2} = x \frac{(273 + 10)}{(273 + 110)} = \frac{283x}{383}$

30. (b) : Average energy per molecule per degree of freedom $= \frac{1}{2}kT$.

31. (a) : Using, $v_{rms} = \sqrt{\frac{3RT}{m}}$

or $\frac{(v_{rms})_1}{(v_{rms})_2} = \sqrt{\frac{T_1}{T_2}}$ ($\because$ R and m are constant)

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According to question, $(v_{rms})_2 = 2(v_{rms})_1$

$$\therefore \quad \frac{(v_{rms})_1}{2(v_{rms})_1} = \sqrt{\frac{300}{T_2}} \Rightarrow \frac{1}{4} = \frac{300}{T_2}$$

$T_2 = 300 \times 4 = 1200$ K.

32. (a) : According to Charle's law, $V \propto T$

or $\frac{V}{T} = \text{constant} = \frac{1}{P}$

As in graph slop of P_1 is more inclined, *i.e.*, $P_1 > P_2$

33. (d) : At high temperature and low pressure the real gas behaves as an ideal gas.

34. (a) : Pressure, $P = \frac{1}{3}\frac{M}{V}v_{rms}^2 = \frac{2}{3}E$

Here, $E = \frac{1}{2}Mv_{rms}^2$ is total internal energy of the gas.

35. (c) : For a monoatomic gas like helium $\gamma_{He} = \frac{5}{3}$

For a diatomic gas like oxygen $\gamma_O = \frac{7}{5}$

i.e., $\gamma_{mix} = \frac{3 \times \gamma_O + 2\gamma_{He}}{(3+2)}$

$$= \frac{3 \times \frac{7}{5} + 2 \times \frac{5}{3}}{5} = \frac{\frac{21}{5} + \frac{10}{3}}{5} = \frac{113}{15 \times 5} = 1.5$$

36. (a) : As partial pressure of a gas in a mixture is the pressure it would exert for the same volume and temperature, if it alone occupied the vessel, therefore, for common V and T.

$P_1V = \mu_1 RT$ and $P_2V = \mu_2 RT$.

Here, 1 and 2 represent for neon gas and oxygen gas respectively.

Now, $\frac{P_1}{P_2} = \frac{\mu_1}{\mu_2} \Rightarrow \frac{\mu_1}{\mu_2} = \frac{3}{2}$ $\left(\text{Given } \frac{P_1}{P_2} = \frac{3}{2}\right)$

If N_1 and N_2 are number of molecules of two gases, then

$\therefore \quad \frac{N_1}{N_2} = \frac{\mu_1}{\mu_2} = \frac{3}{2}$, where $\mu_1 = \frac{N_1}{N_A}$ and $\mu_2 = \frac{N_1}{N_B}$

37. (d) : Pressure exerted by a gas.

$$P = \frac{1}{2}\frac{M}{V}v_{av}^2$$

Since the temperature T is kept constant, v_{av}^2 and V are also constant.

$\therefore \quad P \propto M$ or $\frac{P_2}{P_1} = \frac{M_2}{M_1}$

According to the question,

$$\therefore \quad \frac{P_2}{76} = \frac{\left[M_1 + \left(\frac{50}{100}\right)M_1\right]}{M_1} = \frac{3}{2}$$

$$\Rightarrow \quad P_2 = \frac{3}{2} \times 76 = 114 \text{ cm of mercury}$$

38. (d) : Since there is no loss of energy in the process, therefore, sum of kinetic energy of gases A and B = kinetic energy of mixture,

Temperature of the mixture, $T = \frac{\mu_1 T_1 + \mu_2 T_2}{\mu_1 + \mu_2}$

$$= \frac{2(27+273) + 3(37+273)}{2+3} = \frac{600+930}{5} = \frac{1530}{5}$$

$\therefore \quad = 306$ K $= 306 - 273 = 33$ °C

39. (c) : Using, $PV = nRT$

Since volume is constant

$$\therefore \quad \frac{P_2}{P_1} = \frac{T_2}{T_1} \text{ or } T_1 = T_2 \times \frac{P_1}{P_2} \text{ or } T_1 = (T_1 + 1)\left(\frac{100}{100.4}\right)$$

$T_1 = (T_1 + 1)\, 0.99 \Rightarrow T_1 = 250$ K

40. (c) : Here, $n = \frac{1}{2}$, $c_V = 3$ J g^{-1} K^{-1}, $M = 4$

$\therefore \quad C_V = Mc_V = 4 \times 3 = 12$ mol^{-1} K^{-1}

At constant volume $P \propto T$.

$$\therefore \quad \frac{P_2}{P_1} = \frac{T_2}{T_1} = 2, \; T_2 = 2T_1$$

Rise in temperature $\Delta T = T_2 - T_1 = 2T_1 - T_1 = T_1 = 273$ K

Heat required, $\Delta Q = nC_V \Delta T = \frac{1}{2} \times 12 \times 273 = 1638$ J

41. (a) : In a process PV^x = constant, molar heat capacity is given by $C = \frac{R}{\gamma - 1} + \frac{R}{1-x}$

As the process is $\frac{P}{V}$ = constant,

i.e., PV^{-1} = constant, therefore, $x = -1$.

For an ideal monoatomic gas, $\gamma = \frac{5}{3}$

$$\therefore \quad C = \frac{R}{\frac{5}{3} - 1} + \frac{R}{1-(-1)} = \frac{3}{2}R + \frac{R}{2} = 2R$$

$\Delta Q = nC(\Delta T) = 1(2R)\,(2T_0 - T_0) = 2RT_0$.

42. (c) : Here, $\gamma = \frac{7}{5}$, $P_1 = P$, $d_1 = d$, $P_2 = P'$, $d_2 = d'$

For an adiabatic process, PV^γ = constant

$$\therefore \quad P_1V_1^\gamma = P_2V_2^\gamma$$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^\gamma = \left(\frac{d_2}{d_1}\right)^\gamma, \; \frac{P'}{P} = \left(\frac{d'}{d}\right)^{7/5} = (32)^{7/5}$$

$$\frac{P'}{P} = (2^5)^{7/5} = 2^7 = 128$$

43. (d) : $V_1 = 1500$ m^3, $T_1 = 27$ °C $= 300$ K

$P_1 = 4$ atm, $T_2 = -3$ °C $= 270$ K, $P_2 = 2$ atm

According to ideal gas equation, $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

$$\therefore \quad V_2 = \frac{P_1V_1}{T_1} \times \frac{T_2}{P_2} = \frac{4 \times 1500 \times 270}{300 \times 2} = 2700 \text{ m}^3$$

44. (d) : Average kinetic energy per molecular of a gas = $\frac{3}{2}KT$ = a constant at a given temperature

45. (a) : If an ideal gas is compressed adiabatically, its temperature rises, because heat produced cannot be lost to the surroundings. Each molecule has more KE than before because of collisions of molecules with moving parts of the wall (*i.e.* piston compressing the gas).

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Oscillations

Periodic motion

If a motion repeats itself identically in equal intervals of time, it is said to be periodic motion. The fixed interval of time after which the motion is repeated is called period motion. So, motion of hand of a clock, motion of moon around earth are all examples of periodic motion.

A periodic motion can be either rectilinear or closed or open curvilinear.

In case of periodic motion, force is always directed towards a fixed point which may or may not be on the path of motion.

Oscillatory motion

When a particle or a body moves to and fro or back and forth repeatedly about a fixed point, in a definite interval of time, the motion is called oscillatory or vibratory motion. The motion of the bob of a pendulum, mass attached to a spring are examples of oscillatory motion. All oscillatory motions are periodic motions because each oscillatory motion is completed in a definite interval of time. But all periodic motions may not be oscillatory.

Some terms related to periodic motion

Time period

It is defined as the smallest interval of time after which the motion is repeated. It is denoted by symbol T. Its SI unit is second.

The orbital period of the planet Mercury is 88 earth days. The Halley's comet appears after every 76 years.

Frequency

It is defined as the number of oscillations per unit time. It is denoted by symbol υ.

The relation between υ and T is

$$\upsilon = \frac{1}{T}$$

The SI unit of frequency is hertz(Hz).

$$1 \text{ hertz} = 1 \text{ Hz} = 1 \text{ oscillation per second} = 1 \text{ s}^{-1}.$$

The beat frequency of heart is 1.25 Hz and its period is 0.8 s.

Note: The frequency υ is not necessarily an integer.

Angular frequency

$$\omega = 2\pi\upsilon = \frac{2\pi}{T}$$

The SI unit of ω is rad s^{-1}.

Displacement

It refers to change in physical quantity under consideration with time. It represents changes in physical quantities with time such as position, angle, pressure, electric and magnetic fields etc.

In case of an oscillating simple pendulum, the angle measured from the vertical as a function of time is a displacement variable.

Displacement variable is measured as a function of time, and it can have both positive and negative values. Displacement can be represented by a mathematical function of time. In case of periodic motion, the displacement can be given by

$$x = f(t) = A\cos\omega t \text{ or } y = f(t) = A\sin\omega t$$

where A is called amplitude.

Periodic function

A function $f(t)$ is said to be periodic, if

$$f(t) = f(t + T)$$

where T is the time period of the periodic function.

Any periodic function can be expressed as a superposition of sine and cosine functions of different time periods with suitable coefficients.

$\sin\omega t$, $\cos\omega t$ and $\sin\omega t + \cos\omega t$ are the periodic functions with a period $\frac{2\pi}{\omega}$.

$e^{-\omega t}$ and $\log(\omega t)$ are non periodic functions.

Simple harmonic motion

Simple harmonic motion (SHM) is a special type of oscillation in which the particle oscillates on a straight line, the acceleration of the particle is always directed towards a fixed point on the line and magnitude is proportional to the displacement of the particle from this point. The oscillations may be linear (when displacement is linear) or angular (when displacement is angular). The resultant force on the particle is zero when it is at the centre of oscillation. The centre of oscillation is therefore, the equilibrium position. A force, which takes the particle back towards the equilibrium position, is called a restoring force.

- A simple harmonic motion may be mathematically expressed by a single sinusoidal (sine or cosine) function of time.

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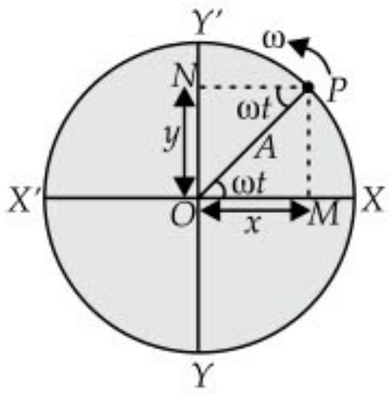
- A simple harmonic motion may also be considered as the projection of a uniform circular motion of any diameter of the circle.
- As shown in figure, let us consider uniform circular motion in a plane with constant angular velocity ω and let at an instant t the particle executing circular motion be at point P making an angle $\theta = \omega t$ with X-axis, then the projection of this circular motion along a diameter YY' is given by



$$y = A\sin\omega t$$

and projection along diameter XX' is given by

$$x = A\cos\omega t$$

Such a motion is simple harmonic motion. The radius A of the reference circle is the maximum value of displacement to and fro about the mean position O and is known as the "amplitude" of SHM.

Kinematics terms in simple harmonic motion

Displacement : Displacement of a particle in the case of SHM is always measured from mean position.

- If the particle is at the mean position at $t = 0$, then displacement $x = A\sin\omega t$.
- If the particle is at the extreme position at $t = 0$, then $x = A\cos\omega t$.
- In general $x = A\sin(\omega t + \phi)$, where ϕ is the initial phase or epoch.

Time period : The time taken by the particle to complete one oscillation is called time period of oscillation. It is denoted by T.

Frequency : The number of oscillations made by the particle in one second is called frequency of oscillations. It is denoted by υ or n. Thus,

$$\upsilon = \frac{1}{T} = \frac{\omega}{2\pi}$$

ω being the angular frequency of the oscillating particle.

Velocity :

As $x = A\sin(\omega t + \phi)$

$$v = \frac{dx}{dt} = A\omega\cos(\omega t + \phi)$$

$$= A\omega[1 - \sin^2(\omega t + \phi)]^{1/2}$$

$$= A\omega\left[1 - \frac{x^2}{A^2}\right]^{1/2} = \omega\sqrt{A^2 - x^2}$$

- At mean position ($x = 0$) velocity is maximum, *i.e.* $v_{max} = A\omega$.
- At extreme positions ($x = \pm A$), velocity is zero, *i.e.* $v = 0$

Acceleration : Acceleration is

$$a = \frac{dv}{dt} = -A\omega^2\sin(\omega t + \phi) = -\omega^2 x$$

- Acceleration is zero at the mean position *i.e.*, $a = 0$, at $x = 0$.
- Acceleration is maximum at extreme position, *i.e.*, $a_{max} = -\omega^2 A$ at $x = A$.

The above expressions also indicate that in SHM, the acceleration is proportional and opposite to the displacement.

Phase relationship between displacement, velocity and acceleration of SHM

As $x = A\sin(\omega t + \phi)$

$$v = A\omega\cos(\omega t + \phi) = A\omega\sin\left(\omega t + \phi + \frac{\pi}{2}\right)$$

and $a = -A\omega^2\sin(\omega t + \phi) = A\omega^2\sin(\omega t + \phi + \pi)$

Thus, we conclude that in SHM, particle velocity is ahead in phase by $\frac{\pi}{2}$ as compared to the displacement and acceleration is further ahead in phase by $\frac{\pi}{2}$.

Energy in simple harmonic motion

The kinetic energy of a particle in SHM is given by

Kinetic energy $K = \frac{1}{2}mv^2 = \frac{1}{2}m\omega^2A^2\cos^2(\omega t + \phi)$

$$= \frac{1}{2}m\omega^2(A^2 - x^2)$$

Kinetic energy of a particle executing SHM is periodic with period $T/2$. It is zero at extreme positions and maximum at mean position.

The potential energy of a particle in SHM is given by

Potential energy $U = \frac{1}{2}kx^2 = \frac{1}{2}kA^2\sin^2(\omega t + \phi)$

$$= \frac{1}{2}m\omega^2A^2\sin^2(\omega t + \phi)$$

Potential energy of a particle executing SHM is periodic with period $T/2$. It is zero at the mean position and maximum at the extreme positions.

Total energy of a particle in SHM is given by

Total energy $E = K + U$

$$= \frac{1}{2}m\omega^2A^2\cos^2(\omega t + \phi) + \frac{1}{2}m\omega^2A^2\sin^2(\omega t + \phi)$$

$$= \frac{1}{2}m\omega^2A^2$$

In SHM, total energy remains constant at all instants and at all displacements. It depends upon the mass, amplitude and frequency of vibration of the particle.

In SHM, at the mean position total energy is in the form of its kinetic energy and at the extreme positions, total energy is in the form of its potential energy.

The average value of kinetic energy or potential energy of a particle in SHM in a time of one complete oscillation,

$$\langle K\rangle = \langle U\rangle = \frac{1}{4}m\omega^2A^2$$

But the average value of total energy of a particle in SHM in one complete oscillation,

$$\langle E\rangle = \frac{1}{2}m\omega^2A^2.$$

If frequency of oscillation in SHM is υ, then

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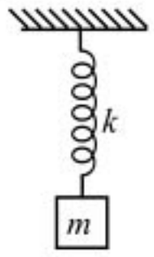
frequency of oscillation of KE
= frequency of oscillation of PE = 2υ.
In SHM, the frequency of oscillation of total energy is zero.

Spring Pendulum

When a mass m is suspended from a massless spring of spring constant k, then its time period is given by

$$T = 2\pi\sqrt{\frac{m}{k}}$$



If M be the mass of the spring and mass m is suspended from it, then the time period is given by

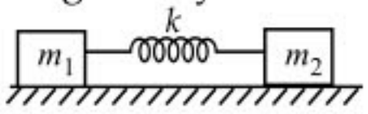
$$T = 2\pi\sqrt{\frac{m + (M/3)}{k}}$$

If a spring of spring constant k is divided into N equal parts and one such part is attached to a mass m, then the time period is given by

$$T = 2\pi\sqrt{\frac{m}{Nk}}$$

If two masses m_1 and m_2 are connected by a spring of spring constant k, then the time period is given by

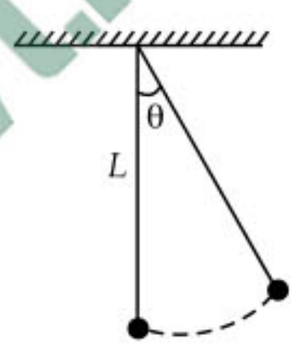
$$T = 2\pi\sqrt{\frac{\mu}{k}}$$



$$\left(\text{where } \mu = \text{reduced mass} = \frac{m_1 m_2}{m_1 + m_2}\right)$$

Simple Pendulum

A point mass (bob or some other object of very small size) when attached to a light rigid rod or light string constitutes a practical simple pendulum.
For small oscillations of simple pendulum about its mean position, the time period of resulting SHM is given by



$$T = 2\pi\sqrt{\frac{L}{g}}$$

Here, L is the length of simple pendulum which is equal to the separation between the point of suspension and centre of mass (gravity) of the bob, and g is acceleration due to gravity.
If the time period of simple pendulum is 2 s, then it is called as second's pendulum.
If temperature of system changes, then time period of simple pendulum changes due to change in length of the simple pendulum.
If the length of simple pendulum is very large, then g can't be taken along vertical direction.

$$\text{In this case } T = 2\pi\sqrt{\frac{1}{g\left(\frac{1}{L} + \frac{1}{R}\right)}}$$

where, R = Radius of earth
If the simple pendulum is placed in some non-inertial frame of reference like an accelerated lift, g is replaced by g_{eff} whose value can be computed by considering the inertial force. In these cases, the equilibrium position may also change.
If a simple pendulum is in a carriage which is accelerating with an acceleration $\vec{a}$, then

$$\vec{g}_{\text{eff}} = \vec{g} - \vec{a}$$

e.g., if the acceleration $\vec{a}$ is upwards, then

$$|\vec{g}_{\text{eff}}| = g + a \text{ and } T = 2\pi\sqrt{\frac{L}{g + a}}$$

If the acceleration $\vec{a}$ is downwards, then (g > a)

$$|\vec{g}_{\text{eff}}| = g - a \text{ and } T = 2\pi\sqrt{\frac{L}{g - a}}$$

If the acceleration $\vec{a}$ is in the horizontal direction, then

$$|\vec{g}_{\text{eff}}| = \sqrt{a^2 + g^2}$$

In a freely falling lift $g_{\text{eff}} = 0$ and $T = \infty$, *i.e.*, the pendulum will not oscillate.
If in addition to gravity one additional force $\vec{F}$ (*e.g.* electrostatic force $\vec{F}_e$) is also acting on the bob, then in that case

$$\vec{g}_{\text{eff}} = \vec{g} + \frac{\vec{F}}{m}$$

Here, m is the mass of the bob.

Formulae of time period for some simple harmonic motion

Conical pendulum

The time period of a conical pendulum is given by

$$T = 2\pi\sqrt{\frac{L\cos\theta}{g}}$$

where L is the length of the string and θ is the angle which the string makes with the vertical.

Torsional pendulum

The time period of a torsional pendulum is given by

$$T = 2\pi\sqrt{\frac{I}{C}}$$

where I is the moment of inertia of the disc about the suspension wire as axis of rotation and C is the restoring torque per unit twist.

$$C = \frac{\pi\eta r^4}{2L}$$

where r is the radius, L is the length and η is the modulus of rigidity of a wire respectively.

Liquid in U-tube

The time period of oscillation of a liquid in U-tube is given by

$$T = 2\pi\sqrt{\frac{L}{2g}} = 2\pi\sqrt{\frac{h}{g}}$$

where L = total length of liquid column in a U-tube,
h = height of liquid column in each limb of U-tube
Also $h = L/2$

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Floating cylinder in a liquid

The time period of oscillation of floating cylinder in a liquid is given by

$$T = 2\pi\sqrt{\frac{m}{A\sigma g}}$$

where m is the mass of a cylinder, A is the area of cross section of a cylinder, σ is the density of a liquid

$$\text{or} \quad T = 2\pi\sqrt{\frac{h\rho}{\sigma g}} = 2\pi\sqrt{\frac{h'}{g}}$$

where h is the height of cylinder of density ρ and σ is the density of a liquid in which cylinder is floating, h' is the height of the cylinder inside the liquid.

Time period of LC oscillations of a circuit containing capacitance C and inductance L is given by

$$T = 2\pi\sqrt{LC}$$

If a wire of length L, area of cross-section A, Young's modulus Y is stretched by suspending a mass m, then the mass can oscillate with time period

$$T = 2\pi\sqrt{\frac{mL}{YA}}$$

If a gas is enclosed in a cylinder of volume V fitted with piston of cross section area A and mass M and the piston is slightly depressed and released, the piston can oscillate with a time period

$$T = 2\pi\sqrt{\frac{MV}{BA^2}}$$

where B is the bulk modulus of elasticity of the gas.

Undamped and damped oscillations

Undamped oscillations

When a simple harmonic system oscillates with a constant amplitude which does not change with time, its oscillations are known as undamped oscillations.

The energy of the system executing undamped oscillations remains constant and is independent of time.

The dissipative forces (*i.e.*, frictional or viscous forces) are not present in the system executing undamped oscillations.

Damped oscillations

When a simple harmonic system oscillates with a decreasing amplitude with time, its oscillations are known as damped oscillations.

The energy of the system executing damped oscillations will go on decreasing with time.

The dissipative forces or damping forces are active in the oscillating system which are generally the frictional or viscous forces.

The damping force is given by $F_d = -bv$,

where, v is the velocity of the oscillator and b is the positive constant and is known as damping constant. –ve sign shows that damping force acts opposite to the velocity at every moment.

The SI unit of b is kg s^{-1}.

The differential equation of damped harmonic oscillator is given by

$$m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = 0$$

The displacement of the damped oscillator at any instant t is given by

$$x(t) = Ae^{-bt/2m}\sin(\omega' t + \phi)$$

where ω′ is the angular frequency of the damped oscillator is given by

$$\omega' = \sqrt{\frac{k}{m} - \frac{b^2}{4m^2}}$$

If the damping constant b is small, then $\omega' \approx \omega$, where ω is the angular frequency of the undamped oscillator.

The mechanical energy E of the damped oscillator at any instant t is given by

$$E = \frac{1}{2}kA^2e^{-bt/m}$$

Free, force oscillations and resonance

Free oscillations

When a system oscillates with its own natural frequency, without the help of any external periodic force, its oscillations are known as free oscillations.

Forced or driven oscillations

When a system oscillates with the help of an external periodic force, other than its own natural angular frequency, its oscillations are known as forced or driven oscillations.

The differential equation of forced damped harmonic oscillator is given by

$$m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = F_0\sin\omega_d t$$

where ω_d is the angular frequency of the external force.

The displacement of the forced damped harmonic oscillator at any instant t is given by

$x(t) = A\sin(\omega_d t - \phi)$

$$\text{with amplitude } A = \frac{F_0}{\{m^2(\omega^2 - \omega_d^2)^2 + \omega_d^2 b^2\}^{1/2}}$$

$$= \frac{F_0}{m\left[(\omega^2 - \omega_d^2)^2 + \left(\frac{\omega_d b}{m}\right)^2\right]^{1/2}}$$

where ω is the natural frequency of the oscillator

$$\text{and } \phi = \tan^{-1}\left[\frac{b\omega_d}{m(\omega^2 - \omega_d^2)}\right]$$

Resonance

It is a special case of forced oscillation. It is the phenomenon in which a system is made to vibrate by external force whose angular frequency is equal to the natural frequency of the system. At resonance, the amplitude of the system is maximum.

Condition for resonance is $\omega = \omega_d$.

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EXAM DRILL

1. A body of mass 5 g is executing SHM about a fixed point O. With an amplitude of 10 cm, its maximum velocity is 100 cm s^{-1}. Its velocity will be 50 cm s^{-1} at a distance (in cm)

(a) 5 (b) $5\sqrt{2}$
(c) $5\sqrt{3}$ (d) $10\sqrt{2}$

2. A mass M, attached to a spring, oscillates with a period of 2 s. If the mass is increased by 4 kg, the time period increases by 1 s. What is the initial mass M?

(a) 3.2 kg (b) 1 kg
(c) 2 kg (d) 8 kg

3. Starting from the origin, a body oscillates simple harmonically with a period of 2 s. After what time will its kinetic energy be 75% of the total energy?

(a) $\frac{1}{12}$s (b) $\frac{1}{6}$s
(c) $\frac{1}{4}$s (d) $\frac{1}{3}$s

4. A body of mass 20 kilogram is suspended by a coil spring of natural length 50.0 cm and force constant 2.0×10^3 N m^{-1}. The stretched length of the spring in cm is ($g = 10$ m s^{-2})

(a) 60.0 cm (b) 55.0 cm
(c) 20.0 cm (d) 10.0 cm

5. A certain simple harmonic vibrator of mass 0.1 kg has a total energy of 10 J. Its displacement from the mean position is 1 cm when it has equal kinetic and potential energies. The amplitude A and frequency υ of vibration of the vibrator are

(a) $A = \sqrt{2}$ cm, $\upsilon = \frac{500}{\pi}$ Hz
(b) $A = \sqrt{2}$ cm, $\upsilon = \frac{1000}{\pi}$ Hz
(c) $A = \frac{1}{\sqrt{2}}$ cm, $\upsilon = \frac{500}{\pi}$ Hz
(d) $A = \frac{1}{\sqrt{2}}$ cm, $\upsilon = \frac{1000}{\pi}$ Hz

6. In a sinusoidal wave, the time required for a particular point to move from maximum displacement to zero displacement is 0.170 s. The frequency of the wave is

(a) 1.47 Hz (b) 0.36 Hz
(c) 0.73 Hz (d) 2.94 Hz

7. The linear density of a vibrating string is 1.3×10^{-4} kg m^{-1}. The equation of a transverse wave propagating through this string is $y = 0.021 \sin(x + 30t)$, where x and y are in metre and t is in second. The approximate tension in the string is

(a) 0.48 N (b) 0.12 N
(c) 1.20 N (d) 4.80 N

8. A weight of mass m is suspended from a fixed point by a light elastic string of modulus 2 mg and natural length 0.5 m. It performs SHM about the equilibrium position in a vertical line. The length of equivalent simple pendulum is

(a) 0.5 m (b) 1 m
(c) 0.25 m (d) 0.75 m

9. What is the effect on the time period of a simple pendulum if the mass of the bob is doubled?

(a) Halved (b) Doubled
(c) Becomes 8 times (d) No effect

10. A body executes simple harmonic motion under the action of a force F_1 with a time period (4/5) s. If the force is changed to F_2 it executes SHM with time period (3/5) s. If both the forces F_1 and F_2 act simultaneously in the same direction on the body, its time period is

(a) $\frac{12}{25}$ s (b) $\frac{24}{25}$ s
(c) $\frac{35}{24}$ s (d) $\frac{25}{12}$ s

11. The time period of a simple pendulum is T. When the length is increased by 10 cm, its period is T_1. When the length is decreased by 10 cm, its period is T_2. Then, relation between T, T_1 and T_2 is

(a) $\frac{2}{T^2} = \frac{1}{T_1^2} + \frac{1}{T_2^2}$ (b) $\frac{2}{T^2} = \frac{1}{T_1^2} - \frac{1}{T_2^2}$
(c) $2T^2 = T_1^2 + T_2^2$ (d) $2T^2 = T_1^2 - T_2^2$

12. Which of the following is not characteristics of SHM oscillations?

(a) The motion is periodic.
(b) The motion is along a straight line about the mean position.
(c) The acceleration of the particle is directed towards the extreme position.
(d) The oscillations are responsible for the energy conversion.

13. Two pendulums X and Y of time periods 4 s and 4.2 s are made to vibrate simultaneously. They are initially in phase. After how many vibrations of X, they will be in the same phase again.

(a) 30 (b) 25
(c) 21 (d) 26

14. A particle starts oscillating simple harmonically from its equilibrium position with time period T. The ratio of kinetic energy and potential energy of the particle at time $t = \frac{T}{12}$ is

(a) 1 : 4 (b) 2 : 1
(c) 3 : 1 (d) 4 : 1

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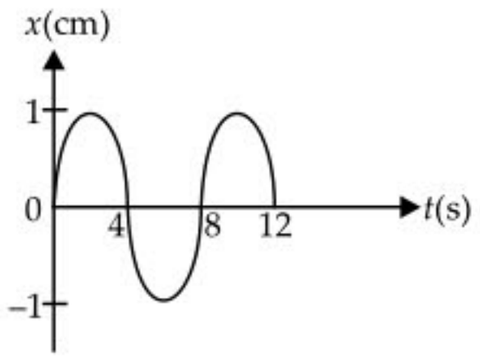
15. The time period of a simple harmonic motion is 8 s. At $t = 0$, it is at its equilibrium position. The ratio of distances travelled by it in the first and second seconds is

(a) $\frac{1}{\sqrt{2}}$ (b) $\frac{1}{\sqrt{2}-1}$

(c) $\frac{1}{\sqrt{3}}$ (d) $\frac{1}{2}$

16. The x-t graph of a particle undergoing simple harmonic motion is as shown in the figure. The acceleration of the particle at $t = \frac{4}{3}$ s is



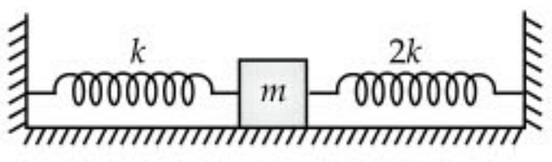
(a) $\frac{\sqrt{3}}{32}\pi^2$ cm s^{-2}

(b) $-\frac{\pi^2}{32}$ cm s^{-2}

(c) $\frac{\pi^2}{32}$ cm s^{-2}

(d) $-\frac{\sqrt{3}}{32}\pi^2$ cm s^{-2}

17. Two springs of spring constants k and $2k$ are connected to a mass m as shown in the figure. Frequency of oscillation is



(a) $\left(\frac{1}{2\pi}\right)\sqrt{\left(\frac{k}{m}\right)}$ (b) $\left(\frac{1}{2\pi}\right)\sqrt{\left(\frac{2k}{m}\right)}$

(c) $\left(\frac{1}{2\pi}\right)\sqrt{\left(\frac{3k}{m}\right)}$ (d) $\left(\frac{1}{2\pi}\right)\sqrt{\left(\frac{m}{k}\right)}$

18. When a body of mass 1.0 kg is suspended from a certain light spring hanging vertically, its length increases by 5 cm. By suspending 2.0 kg block to the spring and if the block is pulled through 10 cm and released, the maximum velocity in it is (Take $g = 10$ m s^{-2})

(a) 0.5 m s^{-1} (b) 1 m s^{-1}

(c) 2 m s^{-1} (d) 4 m s^{-1}

19. A mass oscillates along the x-axis according to the law, $x = x_0 \cos\left(\omega t - \frac{\pi}{4}\right)$. If the acceleration of the particle is written as $a = A\cos(\omega t + \delta)$, then

(a) $A = x_0\omega^2, \delta = \frac{3\pi}{4}$ (b) $A = x_0, \delta = -\frac{\pi}{4}$

(c) $A = x_0\omega^2, \delta = \frac{\pi}{4}$ (d) $A = x_0\omega^2, \delta = -\frac{\pi}{4}$

20. The time period of a simple pendulum of length L measured in an elevator descending with acceleration $\frac{g}{3}$ is

(a) $2\pi\sqrt{\frac{3L}{2g}}$ (b) $\pi\sqrt{\frac{3L}{g}}$

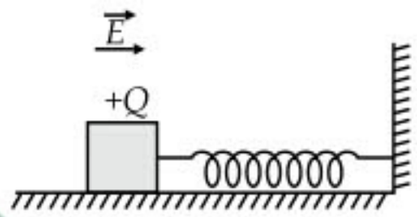
(c) $2\pi\sqrt{\left(\frac{3L}{g}\right)}$ (d) $2\pi\sqrt{\frac{2L}{3g}}$

21. The magnitude of maximum acceleration is π times that of maximum velocity of a simple harmonic oscillator. The time period of the oscillator in seconds is

(a) 4 (b) 2

(c) 1 (d) 0.5

22. A wooden block performs SHM on a frictionless surface with frequency, υ. The block carries a charge $+Q$ on its surface. If now a uniform electric field $\vec{E}$ is switched on as shown, then the SHM of the block will be



(a) of the same frequency and with shifted mean position.

(b) of the same frequency and with the same mean position.

(c) of changed frequency and with shifted mean position.

(d) of changed frequency and with the same mean position.

23. The displacement of a particle varies according to the relation

$x = 4(\cos\pi t + \sin\pi t)$

The amplitude of the particle is

(a) 8 (b) 2

(c) 4 (d) $4\sqrt{2}$

24. A mass M, attached to a horizontal spring, executes SHM with amplitude A_1. When the mass M passes through its mean position then a smaller mass m is placed over it and both of them move together with amplitude A_2. The ratio of $\left(\frac{A_1}{A_2}\right)$ is

(a) $\frac{M+m}{M}$ (b) $\left(\frac{M}{M+m}\right)^{1/2}$

(c) $\left(\frac{M+m}{M}\right)^{1/2}$ (d) $\frac{M}{M+m}$

25. The time period of a particle undergoing SHM is 16 s. It starts motion from the mean position. After 2 s, its velocity is 0.4 m s^{-1}. The amplitude of oscillation is

(a) 1.44 m (b) 0.72 m

(c) 2.88 m (d) 0.36 m

26. A particle is performing simple harmonic motion along x-axis with amplitude 4 cm and time period 1.2 s. The minimum time taken by the particle to move from $x = 2$ to $x = 4$ cm and back again is

(a) 0.4 s (b) 0.3 s

(c) 0.2s (d) 0.36 m

27. A weightless spring of length 60 cm and force constant 100 N m^{-1} is kept straight and unstretched on a smooth horizontal table and its ends are rigidly fixed. A mass of 0.25 kg is attached at the middle of

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the spring and is slightly displaced along the length. The time period of the oscillation of the mass is

(a) $\frac{\pi}{20}$ s (b) $\frac{\pi}{10}$ s

(c) $\frac{\pi}{5}$ s (d) $\frac{\pi}{\sqrt{200}}$ s

28. The displacement of the particle from its mean position (in metre) is given by
$y = 0.2 \sin(10\pi t + 1.5\pi)\cos(10\pi t + 1.5\pi)$.
The motion of the particle is
(a) periodic but not simple harmonic motion
(b) non periodic
(c) simple harmonic motion with period of 0.1 s
(d) simple harmonic motion with period of 0.2 s

29. The kinetic energy of a particle executing SHM will be equal to $(1/8)^{th}$ of its potential energy when its displacement from the mean position is
(where A is the amplitude)
(a) $A\sqrt{2}$ (b) $A/2$
(c) $\frac{2\sqrt{2}}{3}A$ (d) $A\sqrt{\frac{2}{3}}$

30. The length of the simple pendulum which ticks seconds is
(a) 2 m (b) 1.5 m
(c) 1 m (d) 3 m

31. The simple harmonic vibrations of two particles are $y_1 = 5\sin(100t)$ and $y_2 = 4\cos\left(100t + \frac{\pi}{4}\right)$. The phase difference between them is
(a) $\frac{\pi}{4}$ (b) $\frac{\pi}{2}$
(c) π (d) $\frac{3\pi}{4}$

32. A travelling harmonic wave on a string is described by $y = 7.5 \sin(0.005x + 12t)$ in metre. Its time period in second is
(a) $\frac{\pi}{12}$ (b) $\frac{\pi}{6}$
(c) $\frac{\pi}{3}$ (d) $\frac{\pi}{2}$

33. An object of mass 0.2 kg executes simple harmonic motion along the x-axis with a frequency of $(25/\pi)$ Hz. At the position $x = 0.04$ m, the object has kinetic energy of 0.5 J and potential energy 0.4 J. The amplitude of oscillations is
(a) 6 cm (b) 4 cm
(c) 8 cm (d) 2 cm

34. A uniform circular disc of mass 12 kg is held by two identical springs as shown in the figure. When the disc is pressed down slightly and released, it executes SHM with a time period of 2 s. The spring constant of each spring is

(a) 236 N m^{-1} (b) 118.3 N m^{-1}
(c) 59.15 N m^{-1} (d) 318.2 N m^{-1}

35. The length of the second's pendulum is decreased by 0.3 cm when it is shifted to Chennai from London. If the acceleration due to gravity at London is 981 cm s^{-2}, the acceleration due gravity at Chennai is (assume $\pi^2 = 10$)
(a) 981 cm s^{-2} (b) 978 cm s^{-2}
(c) 984 cm s^{-2} (d) 975 cm s^{-2}

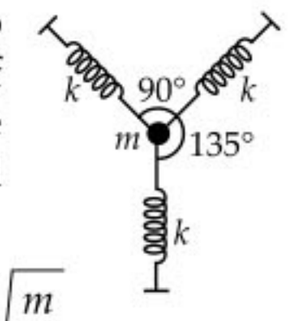
36. A simple pendulum oscillates in a vertical plane. When it passes through the mean position, the tension in the string is 3 times the weight of the pendulum bob. What is the maximum displacement of the pendulum of the string with respect to the vertical?
(a) 30° (b) 45°
(c) 60° (d) 90°

37. A spring 40 mm long is stretched by the application of a force. If 10 N force is required to stretch the spring through 1 mm, the work done in stretching the spring through 40 mm is
(a) 84 J (b) 48 J
(c) 24 J (d) 8 J

38. The period of oscillation of a mass M suspended from a spring of negligible mass is T. If along with it another mass M is also suspended, the period of oscillation will now be
(a) T (b) $\frac{T}{\sqrt{2}}$
(c) $2T$ (d) $\sqrt{2}T$

39. The equation of SHM of a particle is given as $2\frac{d^2x}{dt^2} + 32x = 0$, where x is the displacement from the mean position of rest. The period of its oscillation in seconds is
(a) 4 (b) $\frac{\pi}{2}$
(c) $\frac{\pi}{2\sqrt{2}}$ (d) 2π

40. A particle of mass m is attached to three identical massless springs of spring constant k as shown in the figure. The time period of vertical oscillation of the particle is



(a) $2\pi\sqrt{\frac{m}{k}}$ (b) $2\pi\sqrt{\frac{m}{2k}}$
(c) $2\pi\sqrt{\frac{m}{3k}}$ (d) $\pi\sqrt{\frac{m}{k}}$

41. A simple pendulum has time period T_1. The point of suspension is now moved upward according to the relation $y = Kt^2$. ($K = 1$ m s^{-2}) where y is the vertical displacement. The time period now becomes T_2. The ratio of $\frac{T_1^2}{T_2^2}$ is
(Take $g = 10$ m s^{-2})

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(a) $\frac{6}{5}$ (b) $\frac{5}{6}$

(c) 1 (d) $\frac{4}{5}$

42. A pendulum with length l and bob carries a $-q$ charge. A positive charge $+q$ is held at the point of support. The time period of the bob is

(a) greater than $2\pi\sqrt{l/g}$

(b) less than $2\pi\sqrt{l/g}$

(c) equal to $2\pi\sqrt{l/g}$

(d) equal to $2\pi\sqrt{2l/g}$

43. The total energy of simple harmonic motion is E. What will be the kinetic energy of the particle when displacement is half of the amplitude?

(a) $3E/4$ (b) $E/2$

(c) $E/4$ (d) $E/3$

44. If the displacement (x) and velocity v of a particle executing simple harmonic motion are related through the expression $4v^2 = 25 - x^2$ then its time period (in s) is

(a) π (b) 2π

(c) 4π (d) 6π

45. The maximum velocity of a particle executing simple harmonic motion with an amplitude 7 mm, is 4.4 m s^{-1}. The period of oscillation is

(a) 100 (b) 0.01

(c) 10 (d) 0.1

DAY 13 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ

Wrong marking ⊗ ✓ ◑ ◉

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____

(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. **(c) :** $v_{max} = 100 = a\omega$;

$$\omega = \frac{100}{A} = \frac{100}{10} = 10 \text{ rad s}^{-1}.$$

Velocity of SHM at a distance x is

$$v^2 = \omega^2(A^2 - x^2)$$

or $50^2 = 10^2(10^2 - x^2)$ or $25 = 100 - x^2$

or $x = \sqrt{75} = 5\sqrt{3}$ cm

2. **(a) :** $T = 2 = 2\pi\sqrt{\frac{M}{k}}$ ...(i)

and $2 + 1 = 2\pi\sqrt{\frac{M+4}{k}}$ ...(ii)

Dividing equation (i) by (ii)

or $\frac{4}{9} = \frac{M}{M+4}$ or $4M + 16 = 9M$ or $M = 16/5 = 3.2$ kg

3. **(b) :** Here,

$$\text{K.E.} = \frac{75}{100}E = \frac{75}{100} \times \frac{1}{2}ma^2\omega^2$$

$$\therefore \quad \frac{1}{2}ma^2\omega^2\cos^2\omega t = \frac{75}{100} \times \frac{1}{2}ma^2\omega^2$$

or $\cos^2\omega t = \frac{3}{4}$ or $\cos\omega t = \frac{\sqrt{3}}{2} = \cos\frac{\pi}{6}$

or $\omega t = \frac{\pi}{6}$ or $t = \frac{\pi}{6\omega} = \frac{\pi}{6 \times (2\pi/2)} = \frac{1}{6}$ s

4. **(a) :** Original length of the spring = 50.0 cm

If l is the extension in the spring due to weight F (= 20 kgf)then $l = \frac{F}{k} = \frac{20 \times 10}{2 \times 10^3} = 0.1 \text{ m} = 10 \text{ cm}$

$\therefore$ stretched length = 10 + 50 = 60 cm

5. **(a) :** For a displacement x, the kinetic and potential energies are,

$$\text{K.E.} = \frac{1}{2}m(A^2 - x^2)\omega^2 \text{ and } \text{P.E.} = \frac{1}{2}mx^2\omega^2$$

Each of these $= \frac{10}{2} = 5$ J when $x = 1$ cm

$$\therefore \quad \frac{1}{2}mx^2\omega^2 = \frac{1}{2} \times 0.1 \times (1 \times 10^{-2})^2\omega^2 = 5$$

or $\omega^2 = \frac{10}{0.1 \times 10^{-4}} = 10^6$

or $\omega = 10^3 = 1000 \text{ rad s}^{-1}$

$$T = \frac{2\pi}{\omega} = \frac{\pi}{500} \text{ s}$$

Frequency, $\upsilon = \frac{1}{T} = \frac{500}{\pi} \text{ s}^{-1} = \frac{500}{\pi}$ Hz

$$\text{K.E.} = 5 = \frac{1}{2} \times 0.1[A^2 - (1 \times 10^{-2})^2](10^6)$$

or $A^2 - 10^{-4} = 10^{-4}$

or $A^2 = 2 \times 10^{-4}$ or $A = \sqrt{2} \times 10^{-2}$ m $= \sqrt{2}$ cm

6. **(a) :** From maximum displacement to zero displacement

$t = \frac{T}{4} = 0.170$ s or $T = 4 \times 0.170 = 0.680$ s

$\upsilon = \frac{1}{T} = \frac{1}{0.68} = 1.47$ Hz

7. **(b) :** From the given equation., $\frac{2\pi}{\lambda} = 1$ or $\lambda = 2\pi$

and $\frac{2\pi}{T} = 30, T = \frac{2\pi}{30} = \frac{\pi}{15}, m = 1.3 \times 10^{-4} \text{ kg m}^{-1}$

$$\upsilon = \frac{\lambda}{T} = \sqrt{\frac{T'}{m}}$$

Here T' is tension in string.

$$\therefore \quad T' = \frac{\lambda^2 \times m}{T^2} = \frac{4\pi^2 \times (15)^2 \times 1.3 \times 10^{-4}}{\pi^2} = 0.12 \text{ N}$$

8. **(c) :** Using, $Y = \frac{F}{A} \times \frac{L}{\Delta l}$

or $F = \frac{YA\Delta l}{L} = \frac{2mg}{A} \times \frac{A\Delta l}{L} = \frac{2mg}{L}\Delta l$

As $F \propto \Delta l$ and F is a restoring force, hence the mass m will execute SHM.

Here, spring factor = $\frac{2mg}{L}$ and Inertia factor = m

$$\therefore \quad \text{Time period} = 2\pi\sqrt{\frac{m}{2mg/L}} = 2\pi\sqrt{\frac{(L/2)}{g}}$$

$\therefore$ equivalent length = $\frac{L}{2} = \frac{0.5}{2} = 0.25$ m

9. **(d) :** Time period of a simple pendulum,

$$T = 2\pi\sqrt{\frac{L}{g}}$$

It means T is independent of mass of the bob m. Hence, if mass is doubled, T will not change.

10. **(a) :** $F_1 = -k_1x, \; F_2 = -k_2x$

$$a_1 = -\left(\frac{k_1}{m}\right)x; \; a_2 = -\left(\frac{k_2}{m}\right)x \text{ or } a_1 = -\omega_1^2x; \; a_2 = -\omega_2^2x$$

Resultant force, $F = F_1 + F_2 = -k_1x - k_2x$

or $-kx = -k_1x - k_2x$ or $k = k_1 + k_2$

$$m\omega^2 = m\omega_1^2 + m\omega_2^2$$

or $\omega^2 = \omega_1^2 + \omega_2^2$

or $\left(\frac{2\pi}{T}\right)^2 = \left(\frac{2\pi}{T_1}\right)^2 + \left(\frac{2\pi}{T_2}\right)^2$

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or $\frac{1}{T^2}=\frac{1}{T_1^2}+\frac{1}{T_2^2}$

$$T=\frac{T_1T_2}{\sqrt{T_1^2+T_2^2}}=\frac{\frac{4}{5}\times\frac{3}{5}}{\sqrt{\left(\frac{4}{5}\right)^2+\left(\frac{3}{5}\right)^2}}=\frac{12}{25}\text{ s}$$

11. (c) : Time period of a simple pendulum,

$$T=2\pi\sqrt{\frac{L}{g}}$$

where L is the length of the pendulum.

or $T^2=\frac{4\pi^2L}{g}$ ...(i)

When the length of the pendulum is increased by 10 cm, its length becomes

$\therefore \quad L_1=L+10$

Its time period becomes

$$T_1=2\pi\sqrt{\frac{L_1}{g}}=2\pi\sqrt{\frac{(L+10)}{g}} \qquad ...(ii)$$

when the length of the pendulum decreased by 10 cm, its length becomes

$L_2=L-10$

Its time period becomes

$$T_2=2\pi\sqrt{\frac{L_2}{g}}=2\pi\sqrt{\frac{(L-10)}{g}} \qquad ...(iii)$$

Squaring and adding (ii) and (iii), we get

$$T_1^2+T_2^2=\frac{4\pi^2}{g}[(L+10)+(L-10)]=\frac{4\pi^2}{g}(2L)$$

$$=2\left(\frac{4\pi^2L}{g}\right)=2T^2 \qquad \text{(Using (i))}$$

12. (c) : In SHM, the acceleration is directed towards the mean position.

13. (c) : Let pendulum X makes n vibrations, then the pendulum Y makes one less than n to come in phase again.

$\therefore \quad nT_X=(n-1)T_Y$ or $n4=(n-1)4.2$

$4n=4.2n-4.2$ or $0.2n=4.2$ or $n=21$

14. (c) : In case of SHM, when motion is considered from the equilibrium position, the displacement x at any time t is given by

$x=A\sin\omega t$

At $t=\frac{T}{12}$,

$$x=A\sin\frac{2\pi}{T}\times\frac{T}{12}=\frac{A}{2} \qquad \left(\because\ \omega=\frac{2\pi}{T}\right)$$

Kinetic energy, $K=\frac{1}{2}mv^2=\frac{1}{2}m\omega^2(A^2-x^2)$

$$=\frac{1}{2}m\omega^2\left(A^2-\frac{A^2}{4}\right)=\frac{3}{4}\left(\frac{1}{2}m\omega^2A^2\right)$$

and potential energy, $U=\frac{1}{2}m\omega^2x^2=\frac{1}{2}m\omega^2\left(\frac{A^2}{2}\right)$

$$=\frac{1}{4}\left(\frac{1}{2}m\omega^2A^2\right)$$

$\therefore \quad \frac{K}{U}=\frac{3}{1}$

15. (b) : Here, time period, $T=8$ s

In SHM, if time is considered from equilibrium position, displacement x at any time t is given by

$x=A\sin\omega t$

At $t=1$ s, $x_1=A\sin\omega$ ...(i)

At $t=2$ s, $x_2=A\sin2\omega$ ...(ii)

The distance covered in 2nd second,

$x_2-x_1=A\sin2\omega-A\sin\omega$

The ratio of distance travelled in first second to that in second

$$=\frac{x_1}{x_2-x_1}=\frac{A\sin\omega}{A\sin2\omega-A\sin\omega}$$

$$=\frac{A\sin\left(\frac{2\pi}{T}\right)}{A\sin2\left(\frac{2\pi}{T}\right)-A\sin\left(\frac{2\pi}{T}\right)} \qquad \left(\because\ \omega=\frac{2\pi}{T}\right)$$

$$=\frac{A\sin\left(\frac{2\pi}{8}\right)}{A\sin\left(\frac{4\pi}{8}\right)-A\sin\left(\frac{2\pi}{8}\right)} \qquad (\because\ T=8\text{ s})$$

$$=\frac{\sin\left(\frac{\pi}{4}\right)}{\sin\left(\frac{\pi}{2}\right)-\sin\left(\frac{\pi}{4}\right)}=\frac{\frac{1}{\sqrt{2}}}{1-\frac{1}{\sqrt{2}}}=\frac{1}{\sqrt{2}-1}$$

16. (d) : From graph, $A=1$ cm, $T=8$ s

$$x=A\sin\omega t=A\sin\frac{2\pi}{T}t$$

At $t=\frac{4}{3}$ s, $x=1\sin\frac{2\pi}{8}\times\frac{4}{3}=\sin\frac{\pi}{3}=\frac{\sqrt{3}}{2}$ cm

In SHM,

$$\text{Acceleration}=-\omega^2x=-\frac{4\pi^2}{T^2}\times\frac{\sqrt{3}}{2}\text{ cm s}^{-2}$$

$$=-\frac{4\pi^2}{(8)^2}\times\frac{\sqrt{3}}{2}=-\frac{\sqrt{3}\pi^2}{32}\text{ cm s}^{-2}$$

17. (c) : Here, the two springs are connected in parallel. Their equivalent spring constant is given by

$k'=k_1+k_2=k+2k=3k$

Frequency of oscillation, $\upsilon=\frac{1}{2\pi}\sqrt{\frac{k'}{m}}$ $\therefore$ $\upsilon=\frac{1}{2\pi}\sqrt{\frac{3k}{m}}$

18. (b) : $F=-kx$

For first case, $x=5$ cm $=0.05$ m

and $F=mg=(1.0\text{ kg})(10\text{ m s}^{-2})=10$ N

$\therefore \quad 10=k\times0.05$

or $k=\frac{10}{0.05}=200\text{ N m}^{-1}$

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For second case,
Consider simple harmonic motion

$x = A\sin\omega t$

$$\frac{dx}{dt} = A\omega\cos\omega t$$

$$\left.\frac{dx}{dt}\right|_{max} = A\omega\cos\omega t\,|_{max} = A\omega$$

$$\therefore \quad v_{max} = A\sqrt{\frac{k}{m}} = 0.1\sqrt{\frac{200}{2}} = 0.1\sqrt{100} = 1\ \text{m s}^{-1}$$

19. (a) : Given, $x = x_0\cos(\omega t - \frac{\pi}{4})$

Velocity, $v = \frac{dx}{dt} = -x_0\omega\sin(\omega t - \frac{\pi}{4})$

Acceleration, $a = \frac{dv}{dt} = -x_0\omega^2\cos\left(\omega t - \frac{\pi}{4}\right)$

$$= x_0\omega^2\cos[\pi + (\omega t - \frac{\pi}{4}]$$

$$= x_0\omega^2\cos[\omega t + \frac{3\pi}{4}]$$

Comparing it with acceleration,
$a = A\cos(\omega t + \delta)$, we get

$$A = x_0\omega^2, \delta = \left(\frac{3\pi}{4}\right)$$

20. (a) : The effective acceleration in a lift descending with acceleration $\frac{g}{3}$ is

$$g_{eff} = g - \frac{g}{3} = \frac{2g}{3}$$

Time period of simple pendulum

$$\therefore \quad T = 2\pi\sqrt{\frac{L}{g_{eff}}} = 2\pi\sqrt{\frac{L}{2(g/3)}} = 2\pi\sqrt{\frac{3L}{2g}}$$

21. (b) : $a_{max} = \omega^2 A$
where A is the amplitude of oscillation

$v_{max} = \omega A$
As per question, $a_{max} = \pi v_{max}$
$\therefore \quad \omega^2 A = \pi(\omega A)$ or $\omega = \pi$

Time period, $T = \frac{2\pi}{\omega} = \frac{2\pi}{\pi} = 2\ \text{s}$

22. (a) : As frequency of oscillation of wooden block, $\upsilon = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$, does not depend on constant external force due to electric field, hence the frequency of oscillation will be the same. But due to constant external force, the mean position of the wooden block gets shifted. Hence, option (a) is correct.

23. (d) : $x = 4(\cos\pi t + \sin\pi t)$

$$= 4\sqrt{2}\left[\frac{1}{\sqrt{2}}\cos\pi t + \frac{1}{\sqrt{2}}\sin\pi t\right]$$

$$= 4\sqrt{2}\left[\sin\frac{\pi}{4}\cos\pi t + \cos\frac{\pi}{4}\sin\pi t\right] = 4\sqrt{2}\sin\left(\pi t + \frac{\pi}{4}\right)$$

Standard equation of displacement is

$x = A\sin(\omega t + \phi)$

Comparing the given equation with standard equation, we get

$A = 4\sqrt{2}$

24. (c) : When a mass M attached to a horizontal spring executes SHM, its frequency of oscillation is

$$\upsilon_1 = \frac{1}{2\pi}\sqrt{\frac{k}{M}} \qquad ...(i)$$

When a smaller mass m is placed over mass M, the frequency of oscillation is

$$\upsilon_2 = \frac{1}{2\pi}\sqrt{\frac{k}{(M+m)}} \qquad ...(ii)$$

According to law of conservation of linear momentum

$Mv_1 = (M + m)v_2$ or $MA_1\omega_1 = (M + m)A_2\omega_2$

or $MA_1 2\pi\upsilon_1 = (M + m)A_2 2\pi\upsilon_2$

$$\therefore \quad \frac{A_1}{A_2} = \frac{(M+m)}{M}\times\frac{\upsilon_2}{\upsilon_1}$$

$$= \frac{(M+m)}{M}\times\sqrt{\frac{M}{M+m}} \qquad \text{(Using (i) and (ii))}$$

$$= \sqrt{\frac{M+m}{M}}$$

25. (a) : Here time period of SHM.
$T = 16$ s
Since the motion starts mean position, hence displacement x at time t is

$x = A\sin\omega t$

$\therefore$ Velocity, $v = A\omega\cos\omega t$

At $t = 2$ s, $v = 0.4\ \text{m s}^{-1}$

$$\therefore \quad 0.4 = A\times\frac{2\pi}{16}\cos\frac{2\pi}{16}\times 2 = A\times\frac{2\pi}{16}\times\frac{1}{\sqrt{2}}$$

$$\left[\because \quad \omega = \frac{2\pi}{T} = \frac{2\pi}{16}\ \text{s}^{-1}\right]$$

or $$A = \frac{0.4\times 16\times\sqrt{2}}{2\pi} = \frac{3.2\sqrt{2}}{\pi} = 1.44\ \text{m}$$

26. (a) : When particle is at $x = 2$, the displacement is $x = 4 - 2 = 2$ cm. If t is the time taken by the particle to go from $x = 4$ cm to $x = 2$ cm, then

$$x = A\cos\omega t = A\cos\frac{2\pi t}{T} = A\cos\frac{2\pi t}{1.2}$$

$$\cos\frac{2\pi t}{1.2} = \frac{x}{A} = \frac{2}{4} = \frac{1}{2} = \cos\frac{\pi}{3}$$

or $$\frac{2t}{1.2} = \frac{1}{3} \quad \text{or} \quad t = \frac{1.2}{6} = 0.2\ \text{s}$$

Time taken to move from $x = 2$cm to $x = 4$ cm and back again

$= 2t = 2 \times 0.2\ \text{s} = 0.4\ \text{s}$

27. (a) : Given $K = 100$ N/m; when a mass of 0.25 kg is attached at the middle of spring, it will work as the combination of two equal springs in parallel, each of force constant

$k = 2K = 2 \times 100 = 200$ N/m

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Total force constant of system,

$K' = k + k = 200 + 200 = 400$ N/m

$\therefore$ Time period, $T = 2\pi\sqrt{\frac{M}{K'}} = 2\pi\sqrt{\frac{0.25}{400}} = \frac{\pi}{20}$ s

28. (c) : $y = 0.2\sin(10\pi t + 1.5\pi)\cos(10\pi t + 1.5\pi)$

$= 0.2 \times \frac{1}{2}\sin 2(10\pi t + 1.5\pi)$

$= 0.1\sin(20\pi t + 3\pi)$ ...(i)

$[\because \sin 2\theta = 2\sin\theta\cos\theta]$

Comparing (i) with $y = A\sin\omega t$ which is the equation of SHM, we get

$\omega = 20\pi$ or $\frac{2\pi}{T} = 20\pi$ or $T = 0.1$ s.

The given equation represents S.H.M. with period of 0.1 s.

29. (c) : Kinetic energy when the displacement of the particle is x, is given by

$$K = \frac{1}{2}m\omega^2(A^2 - x^2)$$

Potential energy at this instant is given by

$$U = \frac{1}{2}m\omega^2 x^2$$

According to the condition given in the question

$$K = \frac{1}{8}U$$

$$\Rightarrow \frac{1}{2}m\omega^2(A^2 - x^2) = \frac{1}{8}\cdot\frac{1}{2}m\omega^2 x^2 \text{ or } (A^2 - x^2) = \frac{x^2}{8}$$

On rearranging, we get $x = \frac{2\sqrt{2}}{3}A$

30. (c) : The time period of a simple pendulum is

$$T = 2\pi\sqrt{\frac{l}{g}}$$

where l is the length of the pendulum.

or $l = \frac{gT^2}{4\pi^2}$ ...(i)

The time period of the simple pendulum which ticks seconds is 2 s.

$\therefore$ $T = 2$ s

Substituting in (i), we get

$$l = \frac{(9.8\text{ m s}^{-2})(2\text{ s})^2}{4\times(3.14)^2} = 1\text{ m}$$

31. (d) : Given : $y_1 = 5\sin(100t)$

$$y_2 = 4\cos\left(100t + \frac{\pi}{4}\right) = 4\sin\left(\frac{\pi}{2} + \left(100t + \frac{\pi}{4}\right)\right)$$

$$= 4\sin\left(100t + \frac{3\pi}{4}\right)$$

$\therefore$ Phase difference, $\Delta\phi = \phi_2 - \phi_1$

$$\Delta\phi = \left(100t + \frac{3\pi}{4}\right) - (100t) = \frac{3\pi}{4}$$

32. (b) : The given wave equation is

$y = 7.5\sin(0.005x + 12t)$ ...(i)

The standard wave equation is

$y = A\sin(kx + \omega t)$ ....(ii)

Comparing (i) and (ii), we get, $\omega = 12$

Time period, $T = \frac{2\pi}{\omega} = \frac{2\pi}{12} = \frac{\pi}{6}$ s

33. (a) : Here, $m = 0.2$ kg, $\upsilon = \frac{25}{\pi}$ Hz,

At $x = 0.04$ m, $K = 0.5$ J and $U = 0.4$ J

Since total energy, $E = K + U = 2\pi^2 m\upsilon^2 A^2$

$\therefore$ $0.5 + 0.4 = 2\pi^2 \times 0.2 \times \left(\frac{25}{\pi}\right)^2 A^2$

$\Rightarrow$ $A^2 = \frac{0.9}{0.4\times(25)^2} \Rightarrow A = \frac{3}{2\times 25} = \frac{3}{50}$ m $= 6$ cm

34. (c) : Let k be spring constant of each spring. Here, two springs are connected in parallel. Their effective spring constant is $k_{eff} = k + k = 2k$

$\therefore$ $T = 2\pi\sqrt{\frac{m}{k_{eff}}} = 2\pi\sqrt{\frac{m}{2k}}$ or $T^2 = \frac{4\pi^2 m}{2k}$ or $k = \frac{2\pi^2 m}{T^2}$

$\therefore$ $k = \frac{2\times(3.14)^2\times 12}{4} = 6\times(3.14)^2 = 59.15\text{N m}^{-1}$

35. (b) : As, $T = 2\pi\sqrt{\frac{l}{g}} \Rightarrow l = \frac{gT^2}{4\pi^2}$

For second's pendulum, $T = 2$ s

$\therefore$ $l = \frac{4g}{4\pi^2} = \frac{g}{\pi^2}$

At London, $l = \frac{g}{\pi^2} = \frac{981}{10} = 98.1$ cm ...(i)

Since at Chennai, the length of the pendulum is decreased by 0.3 cm

$\therefore$ $l - 0.3 = \frac{g'}{\pi^2} = \frac{g'}{10}$

or $g' = 10l - 3 = 10 \times 98.1 - 3$ (Using (i))

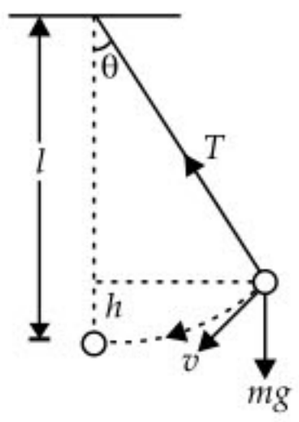
$= 978$ cm s^{-2}

36. (d) : In the mean position, $T = 3mg$

When pendulum displaced, net force,

$T - mg = \frac{mv^2}{l}$ or $3mg - mg = \frac{mv^2}{l}$

$\therefore$ $v = \sqrt{2gl}$



Let maximum angular displacement with vertical be θ. Then

$\frac{1}{2}mv^2 = mgh = mg(l - l\cos\theta)$ or $\frac{1}{2}m\times 2gl = mgl - mgl\cos\theta$

or $\cos\theta = 0$ or $\theta = 90°$

37. (d) : Here $F = 10$ N, $x = 1$ mm,

As $F = -kx$

$\therefore$ $k = \frac{F}{x} = \frac{10\text{ N}}{1\text{ mm}} = \frac{10\text{ N}}{10^{-3}\text{ m}} = 10^4\text{ N m}^{-1}$

$\therefore$ The work done in stretching the spring through 40 mm,

$$W = \frac{1}{2}kx^2 = \frac{1}{2}\times 10^4 \times 0.04 \times 0.04 = 8\text{ J}$$

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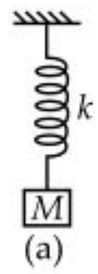
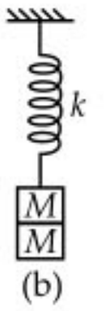
38. (d) : A mass M is suspended from a massless spring of spring constant k as shown in figure (a). Then,
Time period of oscillation is



(a)

$$T = 2\pi\sqrt{\frac{M}{k}} \qquad ...(i)$$

When another mass M is also suspended with it as shown in figure (b). Then,
Time period of oscillation is



(b)

$$T' = 2\pi\sqrt{\frac{M+M}{k}} = 2\pi\sqrt{\frac{2M}{k}}$$

$$= \sqrt{2}\left(2\pi\sqrt{\frac{M}{k}}\right) = \sqrt{2}\,T \qquad \text{(Using (i))}$$

39. (b) : The given equation of SHM is

$$2\frac{d^2x}{dt^2} + 32x = 0 \quad \text{or} \quad \frac{d^2x}{dt^2} + \frac{32}{2}x = 0$$

$$\frac{d^2x}{dt^2} = -16x \qquad ...(i)$$

The standard equation of SHM is

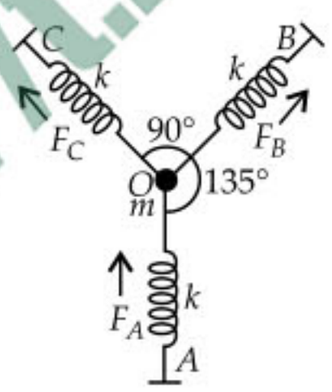
$$\frac{d^2x}{dt^2} = -\omega^2 x \qquad ...(ii)$$

Comparing equations (i) and (ii), we get

$$\omega^2 = 16 \quad \text{or} \quad \omega = 4$$

$$\text{Time period, } T = \frac{2\pi}{\omega} = \frac{2\pi}{4} = \frac{\pi}{2}\text{ s}$$

40. (b) : When the particle of mass m at O is pushed by y in the direction of A, spring A will be compressed by y while springs B and C will be stretched by $y' = y\cos45°$. The total restoring force on the mass m along AO, is



$$F = F_A + F_B\cos45° + F_C\cos45°$$
$$F = -ky - ky'\cos45° - ky'\cos45°$$
$$F = -[ky + ky'\cos45° + ky'\cos45°]$$
$$= -[ky + 2ky'\cos45°]$$
$$= -[ky + 2k(y\cos45°)\cos45°]$$
$$= -[ky + 2ky\cos^2 45°]$$
$$= -[ky + ky]$$
$$F = -2ky \quad ...(i)$$

Comparing (i) with, $F = -k_{eq}\,y$, we get

$$k_{eq} = 2k$$

The time period of vertical oscillation of the particle is

$$T = 2\pi\sqrt{\frac{m}{k_{eq}}} = 2\pi\sqrt{\frac{m}{2k}}$$

41. (a) : Given, $y = Kt^2 \;\therefore\; \frac{dy}{dt} = 2Kt$
and acceleration

$$a = \frac{d^2y}{dt^2} = 2K = 2\times1 = 2\text{ m s}^{-2} \qquad (\because\ K = 1\text{ m s}^{-2})$$

So point of suspension of pendulum is moving upwards with acceleration $a = 2\text{ m s}^{-2}$
Then effective acceleration due to gravity on pendulum, g'
$= (g + a) = 10 + 2 = 12\text{ m s}^{-2}$

$$\therefore\quad T_1 = 2\pi\sqrt{\frac{l}{g}},\ T_2 = 2\pi\sqrt{\frac{l}{g'}} \quad\therefore\quad \frac{T_1^2}{T_2^2} = \frac{g'}{g} = \frac{12}{10} = \frac{6}{5}$$

42. (c)

43. (a) : As kinetic energy,

$$K = \frac{1}{2}m\omega^2(A^2 - y^2) = \frac{1}{2}m\omega^2A^2\left(1 - \frac{y^2}{A^2}\right)$$

According to question,

$$y = \frac{A}{2}$$

$$\therefore\quad K = \frac{1}{2}m\omega^2A^2\left(1 - \frac{1}{4}\right) = \frac{3E}{4} \quad \left(\because\quad E = \frac{1}{2}m\omega^2A^2\right)$$

44. (c) : Given, $4v^2 = 25 - x^2$
Differentiating w.r.t. 't'

$$4\left(2v\cdot\frac{dv}{dt}\right) = -2x\frac{dx}{dt}$$

$$\text{or}\quad 4\frac{dv}{dt} = -x \qquad \left(\because\quad \frac{dx}{dt} = v\right)$$

$$\text{or}\quad 4a = -x \qquad \left(\because\quad \frac{dv}{dt} = a\right)$$

$$\text{or}\quad a = -\frac{1}{4}x$$

$$\because\quad a = -\omega^2x$$

$$\therefore\quad \omega^2 = \frac{1}{4} \text{ and } T = \frac{2\pi}{\omega} = \frac{2\pi}{1/2} = 4\pi\text{ s}$$

45. (b) : As maximum velocity,

$$v_{max} = a\omega = a\frac{2\pi}{T}$$

Here, $a = 7\text{ mm} = 7\times10^{-3}\text{ m}$, $v_{max} = 4.4\text{ m s}^{-1}$

$$\therefore\quad T = \frac{2\pi a}{v_{max}} = \frac{2\times3.14\times7\times10^{-3}}{4.4} = 10^{-2}\text{ s} = 0.01\text{ s}$$

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Waves

Waves

A wave is defined as a disturbance which propagates energy and momentum from one place to the other without the transport of matter.

Waves can be one, two or three dimensional according to the number of dimensions in which they propagate energy. Wave moving along strings are one dimensional, surface waves or ripples on water are two dimensional, while sound or light waves travelling radially out from a point source are three dimensional waves. Waves are of two types :

Mechanical waves

The waves which require some material medium for their propagation are called mechanical waves. Sound waves, seismic waves, waves in strings and springs are examples of mechanical waves. Elasticity and inertia of medium play an important role in propagation of mechanical waves.

Non-mechanical waves

The waves which do not require any material medium for their propagation are called non-mechanical waves. All electromagnetic waves such as γ-rays, X-rays, radio waves, light etc. are non-mechanical.

Any wave whether mechanical or non-mechanical, can be divided into two groups :

- **Longitudinal waves :** Particles of the medium oscillate in the direction of wave motion. They are propagated as compression and rarefaction and are also known as pressure waves. Waves in springs and sound waves in air are example of longitudinal waves.
- **Transverse waves :** In this case the oscillations are at right angles to the direction of wave motion or energy propagation. Waves in strings are transverse. These are propagated as crests and troughs.

A transverse wave travels through a medium in the form of crests and troughs.

A longitudinal wave travels through a medium in the form of compressions and rarefactions. At places of compression the density and pressure are maximum, while at places of rarefaction those are minimum.

Transverse waves can be polarised whereas longitudinal waves cannot be polarised. Hence, transverse or longitudinal nature of a wave can be decided on the basis of polarisation.

Transverse waves can propagate only in medium with shear modulus of elasticity such as solids and strings, but not in fluids.

Longitudinal waves need bulk modulus of elasticity and therefore possible in all media, solids, liquids and gases.

Ultrasonic waves in air produced by a vibrating quartz crystal are longitudinal waves.

Waves produced in a cylinder containing a liquid by moving its piston back and forth are longitudinal waves.

In case of a vibrating tuning fork the waves in the prongs are transverse while in the stem are longitudinal.

Some waves in nature are neither transverse nor longitudinal but a combination of the two. *e.g.* waves produced by a motorboat sailing in water is a combination of both longitudinal and transverse waves.

Various Terms Related to Wave Motion

- **Amplitude :** It is defined as the maximum displacement of an oscillating particle of the medium from the mean position. It is denoted by symbol A.
- **Wavelength :** It is defined as the distance travelled by the wave during the time, the particle of the medium completes one oscillation about its mean position. It may also be defined as the distance between two consecutive points in the same phase of wave motion. It is denoted by symbol λ.

  In case of transverse wave

  λ = distance between two consecutive crests and troughs.

  In case of longitudinal waves

  λ = distance between two consecutive compressions and rarefactions.
- **Time period :** It is defined as the time taken by a particle to complete one oscillation about its mean position. It is denoted by symbol T.
- **Frequency :** It is defined as the number of oscillations made by the particle in one second. It is denoted by symbol υ.

$$\upsilon = \frac{1}{T}$$

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- **Wave speed or speed of a wave :** It is defined as the distance travelled by the wave in one second. It is denoted by symbol v and is given by

  $v = \upsilon\lambda$ ....(i)

  As the speed of a wave is related to its wavelength and frequency by the equation (i) but it is determined by the properties of the medium.
- **Intensity of a wave :** It is defined as the amount of energy flow per unit area per unit time in a direction perpendicular to the propagation of wave. It is denoted by the symbol I and is given by

  $I = 2\pi^2\upsilon^2A^2\rho v$

  where υ is the frequency, A is the amplitude, v is the velocity of the wave, ρ is the density of the medium.

  The SI unit of intensity is W m^{-2}.

  Dimensional formula of intensity of a wave is $[ML^0T^{-3}]$.
- **Energy density :** It is defined as amount of energy flow per unit volume. It is denoted by symbol u and is given by $u = 2\pi^2A^2\upsilon^2\rho$

  where υ is the frequency, A is the amplitude and ρ is the density of the medium.

  The SI unit of energy density is joule/m^3.

  Dimensional formula of energy density is $[ML^{-1}T^{-2}]$.

Equation of Plane Progressive Wave

Equation of plane progressive wave travelling along the +ve direction of x-axis is given by $y(x, t) = A\sin(\omega t - kx + \phi)$

where y = displacement of a particle at time t

A = amplitude of the wave,

ω = angular frequency = $2\pi\upsilon = 2\pi\frac{1}{T}$

k = propagation constant or angular wave number = $\frac{2\pi}{\lambda}$

ϕ = phase constant or initial phase.

Phase of the wave is the argument $(\omega t - kx + \phi)$ of the oscillatory term $\sin(\omega t - kx + \phi)$.

- **Wave velocity,** $v = \frac{\omega}{k}$.

  It depends only on the nature of the medium in which the wave propagates.
- **Slope of the wave,** $\frac{dy}{dx} = -kA\cos(\omega t - kx + \phi)$
- **Particle velocity,**

  $v_{particle} = \frac{dy}{dt} = \omega A\cos(kx - \omega t + \phi) = -\left(\frac{\omega}{k}\right)\frac{dy}{dx}$

  or $v_{particle}$ = –wave velocity × slope of the wave
- **Particle acceleration,** $a = \frac{d^2y}{dt^2} = -\omega^2y$

Equation of plane progressive wave travelling along negative direction of x-axis is given by

$y = A\sin(\omega t + kx + \phi)$

The differential equation of one dimensional progressive wave is given by

$$\frac{\partial^2y}{\partial t^2} = v^2\frac{\partial^2y}{\partial x^2}$$

Relationship Between Phase Difference, Path Difference and Time Difference

$$\text{Phase difference} = \frac{2\pi}{\lambda} \times \text{path difference}$$

$$\text{Phase difference} = \frac{2\pi}{T} \times \text{time difference}$$

A path difference of λ corresponds to a phase difference of 2π radian.

To calculate phase difference between two waves, the equation of both waves must be in sine form or in cosine form.

Displacement and Pressure Waves

A longitudinal sound wave can be expressed either in terms of the longitudinal displacement of the particles of the medium or in terms of excess pressures produced due to compression or rarefection. The first type is called the displacement wave and the second type the pressure wave.

Equation of displacement wave, $y = A\sin(\omega t - kx)$

Equation of pressure wave, $P = P_m\cos(\omega t - kx)$

Here P_m = amplitude of pressure wave.

Speed of Transverse Wave

Speed of a transverse waves on a stretched string is given by

$$v = \sqrt{\frac{T}{\mu}}$$

where T is the tension in the string, μ is the mass per unit length of the string called **linear density**.

Speed of a transverse wave in a solid is given by

$$v = \sqrt{\frac{\eta}{\rho}}$$

where η is the modulus of rigidity, ρ is the density of a solid.

Speed of Longitudinal Wave

Speed of a longitudinal wave in a medium is given by

$$v = \sqrt{\frac{E}{\rho}}$$

where E is the modulus of elasticity and ρ is the density of the medium.

Speed of a longitudinal wave in a metallic bar is given by

$$v = \sqrt{\frac{Y}{\rho}}$$

where Y is the Young's modulus and ρ is the density of material of a metallic bar.

Speed of a longitudinal wave in a fluid is given by

$$v = \sqrt{\frac{B}{\rho}}$$

where B is the bulk modulus and ρ is density of a fluid.

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Newton's Formula

Newton assumed that propagation of sound wave in gas is an isothermal process. Therefore, according to Newton, speed of sound in gas is given by

$$v = \sqrt{\frac{P}{\rho}}$$

where P is the pressure of the gas and ρ is the density of the gas.

According to the Newton's formula, the speed of sound in air at N.T.P. is 280 m s^{-1}. But the experimental value of the speed of sound in air at N.T.P. is 332 m s^{-1}. Newton could not explain this large difference. Newton's formula was corrected by Laplace.

Laplace's Correction

Laplace assumed that propagation of sound wave in gas is an adiabatic process. Therefore, according to Laplace, speed of sound in a gas is given by

$$v = \sqrt{\frac{\gamma P}{\rho}}$$

According to Laplace's correction the speed of sound in air at N.T.P. is 331.3 m s^{-1}. This value agrees fairly well with the experimental values of the speed of sound in air at N.T.P.

Speed of sound in a gas, $v = \sqrt{\frac{\gamma}{3}}\, v_{rms}$.

Principle of Superposition of Waves

When two or more waves travel in a medium in such a way that each wave represents its separate motion individually, then the resultant displacement of particle of the medium at any time is equal to the vector sum of the individual displacements. This phenomenon is known as principle of superposition of waves.

If $y_1, y_2, y_3, ..., y_n$ are the displacements at a point due to the n waves, then the resultant displacement at that point is given by

$$y = y_1 + y_2 + y_3 + ... + y_n$$

The superposition of waves give rise to following three phenomena :

- Interference
- Stationary waves
- Beats

Stationary Waves

When two waves of same frequency, wavelength and amplitude travel in opposite directions at same speed, their superposition gives rise to a new type of waves known as stationary waves or standing waves. Energy does not propagate in this type of wave hence, it is named as stationary wave.

Stationary waves are of two types :

- Longitudinal stationary waves
- Transverse stationary waves

Longitudinal stationary waves : It is produced in

- Organ pipe
- Resonance tube

Transverse stationary waves : It is produced in

- Stretched string
- Sonometer

Equation of a stationary wave is given by

$$y = (2A\sin kx)\cos\omega t$$

Stationary waves are characterised by nodes and antinodes.

Nodes are the points for which the amplitude is minimum whereas antinodes are the points for which the amplitude is maximum.

In a stationary wave nodes and antinodes are formed alternately and distance between them is $\lambda/4$.

At antinodes, displacement and velocity is maximum.

At nodes, displacement and velocity is zero.

Distance between two consecutive nodes or antinodes is $\lambda/2$. Distance between a node and adjoining antinode is $\lambda/4$.

Vibrations in a stretched string of length l fixed at both ends

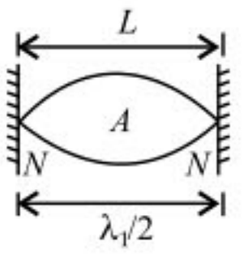
Speed of waves in a stretched string is given by

$$v = \sqrt{\frac{T}{\mu}}$$

where T is the tension of the string, μ is the mass per unit length of the string.

Fundamental mode or first mode,

$$\lambda_1 = 2L$$

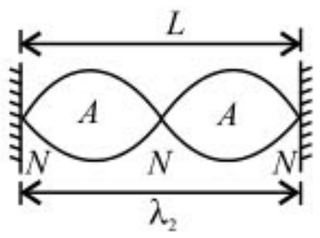


Fundamental frequency

$$\upsilon_1 = \frac{v}{\lambda_1} = \frac{v}{2L} = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$$

This frequency is called first harmonic.

Second mode, $\lambda_2 = L$



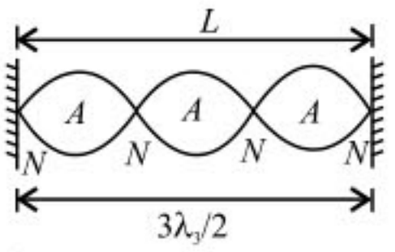
Frequency $\upsilon_2 = \frac{v}{\lambda_2} = \frac{v}{L} = 2\upsilon_1$

This frequency is called second harmonic or first overtone.

Third mode, $\lambda_3 = \frac{2L}{3}$

Frequency

$$\upsilon_3 = \frac{v}{\lambda_3} = \frac{3v}{2L} = 3\upsilon_1$$



This frequency is called third harmonic or second overtone.

For the n^{th} mode, $\lambda_n = \frac{2L}{n}$

Frequency of n^{th} mode

$$\upsilon_n = \frac{v}{\lambda_n} = \frac{nv}{2L} = n\upsilon_1 = \frac{n}{2L}\sqrt{\frac{T}{\mu}} \text{ where } n = 1, 2, 3, ...$$

This frequency is called nth harmonic or $(n-1)^{th}$ overtone.

Note : In general, $\upsilon_p = \frac{p}{2L}\sqrt{\frac{T}{\mu}}$, where p = number of loops.

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Laws of vibrating stretched string

The fundamental frequency of a stretched string is given by $\upsilon = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$.

- Law of length, $\upsilon \propto \frac{1}{L}$ when T and μ are constants.
- Law of tension, $\upsilon \propto \sqrt{T}$ when L and μ are constants
- Law of mass, $\upsilon \propto \frac{1}{\sqrt{\mu}}$ when L and T are constants

Note : If ρ is the density of the material of the string and D is the diameter of string, then mass per unit length, $\mu = \frac{\pi D^2 \rho}{4}$.

$$\therefore \quad \upsilon = \frac{1}{2L}\sqrt{\frac{4T}{\pi D^2 \rho}} = \frac{1}{LD}\sqrt{\frac{T}{\pi\rho}}.$$

Laws of vibration of stretched string can be verified experimentally by using a sonometer.

Melde's Experiment

In longitudinal mode, the prongs of the tuning fork vibrate in a direction parallel to the length of string.

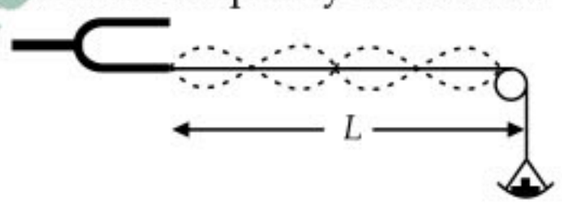
In the longitudinal mode when fork completes one vibration, the string completes only half the vibration. So, the frequency of the string is one half of that of the fork.

$$\upsilon_L = \frac{p}{L}\sqrt{\frac{T}{\mu}}$$

In transverse mode, the prongs of the tuning fork vibrate in a direction perpendicular to the length of the string.

In the transverse mode of vibration when fork completes one vibration, the string also completes one vibration. So, the frequency of the string is equal to the frequency of the fork.

$$\upsilon_T = \frac{p}{2L}\sqrt{\frac{T}{\mu}} = \frac{\upsilon_L}{2}.$$



The number of loops in the transverse mode is twice that in the longitudinal mode.

Vibrations of a closed organ pipe

In a closed organ pipe, one end is closed and other end is open.

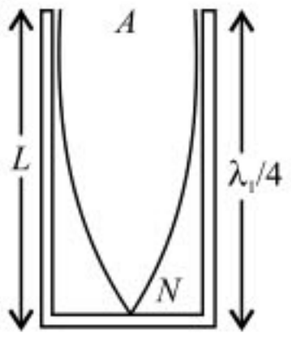
In a closed organ pipe, the closed end is always a node while the open end is always an antinode.

Fundamental mode, or first mode $\lambda_1 = 4L$ where L is the length of the pipe.

Fundamental frequency

$$\upsilon_1 = \frac{v}{\lambda_1} = \frac{v}{4L}$$

where v is the speed of sound in air.



This frequency is called first harmonic.

Second mode, $\lambda_2 = \frac{4L}{3}$

Frequency, $\upsilon_2 = \frac{v}{\lambda_2} = \frac{3v}{4L} = 3\upsilon_1$

This frequency is called third harmonic or 1st overtone.

Third mode, $\lambda_3 = \frac{4L}{5}$

Frequency, $\upsilon_3 = \frac{v}{\lambda_3} = \frac{5v}{4L} = 5\upsilon_1$

This frequency is called fifth harmonic or second overtone.

$\upsilon_1 : \upsilon_2 : \upsilon_3 = 1 : 3 : 5$

Only odd harmonics are present.

For n^{th} mode, $\lambda_n = \frac{4L}{(2n-1)}$

Frequency, $\upsilon_n = \frac{v}{\lambda_n} = \frac{v(2n-1)}{4L} = (2n-1)\upsilon_1$

where $n = 1, 2, 3, ...$

This frequency is called $(2n - 1)^{th}$ harmonic or $(n - 1)^{th}$ overtone.

Vibration of an open organ pipe

In an open organ pipe, both ends are open.

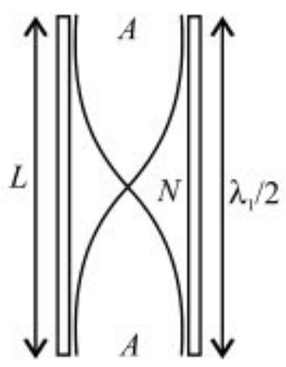
In an open organ pipe, at both ends there will be antinodes.

Fundamental mode or first mode, $\lambda_1 = 2L$ where L is the length of the pipe.

Fundamental frequency

$$\upsilon_1 = \frac{v}{\lambda_1} = \frac{v}{2L}$$

where v is the speed of sound in air.



This frequency is called first harmonic.

Second mode, $\lambda_2 = L$

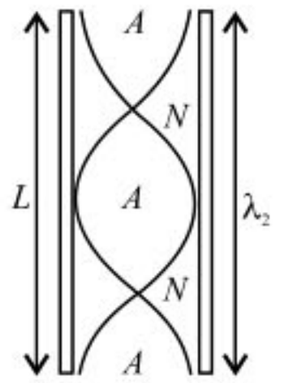
Frequency, $\upsilon_2 = \frac{v}{\lambda_2} = \frac{v}{L} = 2\upsilon_1$

This frequency is called second harmonic or first overtone.

Third mode, $\lambda_3 = \frac{2L}{3}$

Frequency,

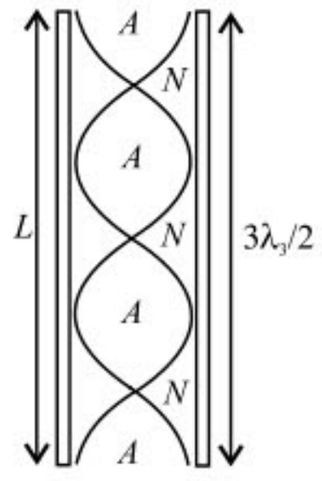
$$\upsilon_3 = \frac{v}{\lambda_3} = \frac{3v}{2L} = 3\upsilon_1$$



This frequency is called third harmonic or second overtone.

$\upsilon_1 : \upsilon_2 : \upsilon_3 = 1 : 2 : 3$

Hence in open pipe all harmonics are present, whereas in a closed pipe only odd harmonics are present.



For n^{th} mode, $\lambda_n = \frac{2L}{n}$

Frequency, $\upsilon_n = \frac{v}{\lambda_n} = \frac{nv}{2L} = n\upsilon_1$, where $n = 1, 2, ...$

This frequency is called n^{th} harmonic or $(n - 1)^{th}$ overtone.

The fundamental frequency of an open organ pipe is twice that of a closed organ pipe of the same length.

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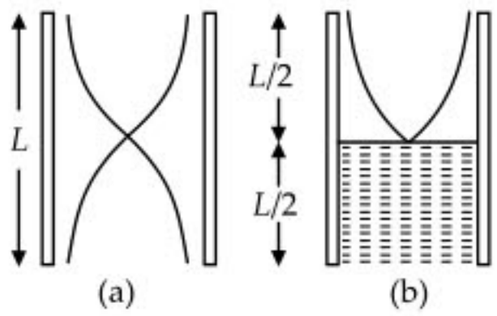
If an open pipe of length L is half submerged in water, it will become a closed organ pipe of length half that of open pipe as shown in figures (a) and (b). So its frequency will become



$$v_C = \frac{v}{4(L/2)} = \frac{v}{2L} = v_O.$$

i.e., equal to that of open pipe, *i.e.*, frequency will remain unchanged.

End correction

The antinode at the open end of a pipe is not formed exactly at the open end but a little outside. This is called the end correction. This is denoted by e and is given by

$e = 0.6r$

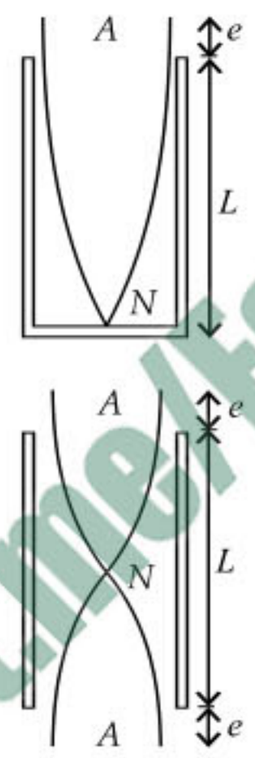
where r is the radius of the pipe. If L is the length of pipe then for closed pipe L is replaced by $L + e$ while for open pipe L is replaced by $L + 2e$.

Due to the end correction the fundamental frequency of a closed organ pipe is given by

$$\upsilon_C = \frac{v}{4[L+e]} = \frac{v}{4[L+0.6r]}$$

Due to the end correction, the fundamental frequency of an open pipe is given by

$$\upsilon_O = \frac{v}{2[L+2e]} = \frac{v}{2[L+1.2r]}$$



Speed of sound in air at room temperature using resonance tube is given by

$v = 2\upsilon(L_2 - L_1)$

where, υ = frequency of the tuning fork

L_1 = first resonance length, L_2 = second resonance length

End correction $e = \dfrac{L_2 - 3L_1}{2}$

Beats

When two waves of nearly equal (but not exactly equal) frequencies travelling with same speed in the same direction superpose on each other, they give rise to beats.

Beat frequency

It is defined as number of beats heard per second.

Beat frequency = no. of beats/sec = $(\upsilon_1 - \upsilon_2)$

= difference in frequencies.

Applications of the Phenomenon of Beats

- The phenomenon of beats is used to determine frequency of a tuning fork.
- The phenomenon of beats is used in tuning of musical instruments.
- The phenomenon of beats is used in detecting the presence of dangerous gases in mines.
- The phenomenon of beats is used in radio reception in many ways.

Note : Loading a tuning fork with wax decreases its frequency while filing a tuning fork increases its frequency.

Tuning fork is a source of sound of single frequency and frequency of a tuning fork of arm length L and thickness d in the direction of vibration is given by

$$\upsilon = \left[\frac{d}{L^2}\right] v = \frac{d}{L^2}\sqrt{\frac{Y}{\rho}} \qquad \left[\because v = \sqrt{\frac{Y}{\rho}}\right]$$

where Y is the Young's modulus and ρ is the density of the material of the tuning fork.

Doppler's Effect

When a source of sound or an observer or both are in relative motion, there is an apparent change in the frequency of sound as heard by the observer. This phenomenon is known as Doppler's effect.

According to Doppler's effect the apparent frequency heard by the observer is given by

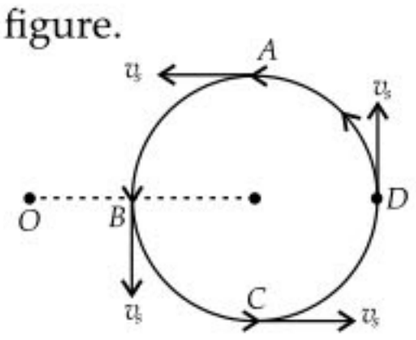
$$\upsilon' = \upsilon\left[\frac{v \pm v_o}{v \mp v_s}\right]$$

where v_s, v_o and v are the speed of source, observer and sound relative to air.

The upper sign on v_s (or v_o) is used when source (observer) moves towards the observer (source) while lower sign is used when it moves away.

If the wind blows with speed v_w in the direction of sound, v is replaced by $v + v_w$ in the above equation. If the wind blows with speed v_w in a direction opposite to that of sound, v is replaced by $v - v_w$ in the above equation.

When a source is revolving in a circle and observer is stationary outside, as shown in the figure.



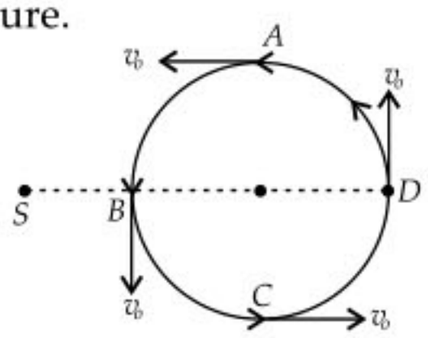
$$\text{At } A, \upsilon_{max} = \frac{v\upsilon}{v - v_s}$$

$$\text{At } C, \upsilon_{min} = \frac{v\upsilon}{v + v_s}$$

Beat frequency = $\upsilon_{max} - \upsilon_{min}$.

There is no Doppler effect at B and D.

When an observer is revolving in a circle with a stationary source outside, as shown in the figure.



$$\text{At } A, \upsilon_{max} = \frac{(v + v_o)\upsilon}{v}$$

$$\text{At } C, \upsilon_{min} = \frac{(v - v_o)\upsilon}{v}$$

Beat frequency = $\upsilon_{max} - \upsilon_{min}$.

There is no Doppler effect at B and D.

If source and observer both are stationary *i.e.* $v_s = v_o = 0$ then $\upsilon' = \upsilon$. Similarly, if source and observer both are moving in the same direction with same speed, *i.e.* $v_s = v_o$, then $\upsilon' = \upsilon$. Thus it is clear that if there is no relative motion between the source and the observer then there is no Doppler effect.

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EXAM DRILL

1. A wire stretched between two rigid supports vibrates in its fundamental mode with a frequency of 45 Hz. The mass of the wire is 3.5×10^{-2} kg and its linear mass density is 4.0×10^{-2} kg m^{-1}. What is the speed of a transverse wave on the string?

(a) 69 m s^{-1} (b) 79 m s^{-1}
(c) 89 m s^{-1} (d) 99 m s^{-1}

2. An open pipe is in resonance in 2nd harmonic with frequency υ_1. Now one end of the tube is closed and frequency is increased to υ_2 such that the resonance again occurs in n^{th} harmonic. Choose the correct option.

(a) $n = 3,\ \upsilon_2 = \frac{3}{4}\upsilon_1$ (b) $n = 3,\ \upsilon_2 = \frac{5}{4}\upsilon_1$
(c) $n = 5,\ \upsilon_2 = \frac{5}{4}\upsilon_1$ (d) $n = 5,\ \upsilon_2 = \frac{3}{4}\upsilon_1$

3. The extension in a string, obeying Hooke's law, is x. The speed of sound in the stretched string is v. If the extension in the string is increased to $1.5x$, the speed of sound will be

(a) $1.22v$ (b) $0.61v$
(c) $1.50v$ (d) $0.75v$

4. Velocity of sound in air is 320 m s^{-1}. A pipe closed at one end has a length of 1 m. Neglecting end corrections, the air column in the pipe can resonate for sound of frequency

(a) 80 Hz (b) 260 Hz
(c) 320 Hz (d) 500 Hz

5. A wave equation is given by $y = 5\sin\frac{\pi}{2}(100t - x)$; where x and y are in metre and time is in second. The period of the wave in second will be

(a) 0.04 (b) 0.01
(c) 1 (d) 5

6. An organ pipe open at one end is vibrating in first overtone and is in resonance with another pipe open at both ends and vibrating in third harmonic. The ratio of length of two pipes is

(a) 1 : 2 (b) 4 : 1
(c) 8 : 3 (d) 3 : 8

7. A tuning fork A produces 4 beats s^{-1} with another tuning fork B of frequency 320 Hz. On filing one of the prongs of A, 4 beats s^{-1} are again heard when sounded with the same fork B, the frequency of the fork A before filing is

(a) 328 Hz (b) 316 Hz
(c) 324 Hz (d) 320 Hz

8. Two strings A and B are slightly out tune and produces beats of frequency 5 Hz. Increasing the tension in B reduces the beat frequency to 3 Hz. If the frequency of string A is 450 Hz, calculate the frequency of string B is

(a) 460 Hz (b) 455 Hz
(c) 445 Hz (d) 440 Hz

9. A resonance pipe is open at both ends and 30 cm of its length is in resonance with an external frequency 1.1 kHz. If the speed of sound is 330 m s^{-1} which harmonic is in resonance?

(a) first (b) second
(c) third (d) fourth

10. A bat flies at a steady speed of 4 m s^{-1} emitting a sound of $\upsilon = 90 \times 10^3$ Hz. It is flying horizontally towards a vertical wall. The frequency of the reflected sound as detected by the bat will be
(Take velocity of sound in air as 330 m s^{-1}).

(a) 88.1×10^3 Hz (b) 87.1×10^3 Hz
(c) 92.1×10^3 Hz (d) 89.1×10^3 Hz

11. The equation of a progressive wave is given by $y = 5\sin(100\pi t - 0.4\pi x)$ where y and x are in m and t is in s.

(1) The amplitude of the wave is 5 m.
(2) The wavelength of the wave is 5 m.
(3) The frequency of the wave is 50 Hz.
(4) The velocity of the wave is 250 m s^{-1}.

Which of the following statements are correct?

(a) (1), (2) and (3) (b) (2) and (3)
(c) (1) and (4) (d) All are correct

12. A stone is dropped into a pond from the top of the tower of height h. If v is the speed of sound in air, then the sound of splash will be heard at the top of the tower after a time

(a) $\sqrt{\frac{2h}{g}} + \frac{h}{v}$ (b) $\sqrt{\frac{2h}{g}} - \frac{h}{v}$
(c) $\sqrt{\frac{2h}{g}}$ (d) $\sqrt{\frac{2h}{g}} + \frac{2h}{v}$

13. A string of mass 2.5 kg is under a tension of 200 N. The length of the stretched string is 20 m. If the transverse jerk is struck at one end of the string, the disturbance will reach the other end in

(a) 0.5 s (b) 1 s
(c) 1.5 s (d) 2 s

14. A steel rod of length 100 cm is clamped at the middle. The frequency of the fundamental mode for the longitudinal vibrations of the rod is
(Speed of sound in steel = 5 km s^{-1})

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(a) 1.5 kHz (b) 2 kHz
(c) 2.5 kHz (d) 3 kHz

15. At what temperature will the speed of sound in air be 3 times its value at 0°C?
(a) 1184°C (b) 1148°C
(c) 2184°C (d) 2148°C

16. A travelling wave is represented by the equation $y = \frac{1}{10}\sin(60t + 2x)$, where x and y are in metres and t is in seconds. This represents a wave
(1) travelling with a velocity of 30 m s^{-1}
(2) of frequency $\frac{30}{\pi}$ Hz
(3) of wavelength π m
(4) of amplitude 10 cm
(5) moving in the positive x direction
Pick out the correct statements from the above.
(a) 1, 2, 4 (b) 3, 4, 5
(c) 1, 2, 3, 4 (d) All

17. For the travelling harmonic wave
$y(x, t) = 2\cos 2\pi(10t - 0.008x + 0.35)$
where x and y are in cm and t is in s. The phase difference between oscillatory motion of two points separated by a distance of 0.5 m is
(a) 0.2π rad (b) 0.4π rad
(c) 0.6π rad (d) 0.8π rad

18. The transverse displacement of a string clamped at its both ends is given by $y(x, t) = 0.06\sin\left(\frac{2\pi}{3}x\right)\cos(120\pi t)$
where x and y are in m and t in s. The length of the string is 1.5 m and its mass is 3×10^{-2} kg. The tension in the string is
(a) 324 N (b) 648 N
(c) 832 N (d) 972 N

19. Which of the following statements is incorrect for a stationary wave?
(a) Every particle has a fixed amplitude which is different from the amplitude of its nearest particle.
(b) All the particles cross their mean position at the same time.
(c) All the particles are oscillating with same amplitude.
(d) There is no net transfer of energy across any plane.

20. When a string fixed at its both ends vibrates in 1 loop, 2 loops, 3 loops and 4 loops, the frequencies are in the ratio
(a) 1 : 1 : 1 : 1 (b) 1 : 2 : 3 : 4
(c) 4 : 3 : 2 : 1 (d) 1 : 4 : 9 : 16

21. A pipe 17 cm long is closed at one end. Which harmonic mode of the pipe resonates a 1.5 kHz source?
(Speed of sound in air = 340 m s^{-1})
(a) First (b) Third
(c) Fifth (d) Seventh

22. Sound waves of wavelength λ travelling in a medium with a speed of v enter into another medium where its speed is $2v$. Wavelength of sound waves in the second medium is
(a) λ (b) $\frac{\lambda}{2}$
(c) 2λ (d) 4λ

23. Two sitar strings A and B are slightly out of tune and produce beats of frequency 5 Hz. When the tension in the string B is slightly increased, the beat frequency is found to reduce to 3 Hz. If the frequency of string A is 427 Hz, the original frequency of string B is
(a) 422 Hz (b) 424 Hz
(c) 430 Hz (d) 432 Hz

24. If v_{rms} is the rms speed of molecules in a gas and v is the speed of sound waves in the gas, then the ratio $\frac{v_{rms}}{v}$ is
(a) $\sqrt{\frac{3}{\gamma}}$ (b) $\sqrt{\frac{\gamma}{3}}$
(c) $\sqrt{3\gamma}$ (d) $\frac{\sqrt{3}}{\gamma}$

25. An organ pipe of length L open at both ends is found to vibrate in its first harmonic when sounded with a tuning fork of 480 Hz. What should be the length of a pipe closed at one end, so that it also vibrates in its first harmonic with the same tuning fork?
(a) $\frac{L}{4}$ (b) $\frac{L}{2}$
(c) L (d) $2L$

26. A closed organ pipe and an open organ pipe of same length produce 2 beats s^{-1} while vibrating in their fundamental modes. The length of the open organ pipe is halved and that of closed pipe is doubled. The number of beats produced per second while vibrating in the fundamental mode is
(a) 2 (b) 6
(c) 8 (d) 7

27. When interference of light takes place
(a) energy is created in the region of maximum intensity
(b) energy is destroyed in the region of maximum intensity
(c) conservation of energy holds good and energy is redistributed
(d) conservation of energy does not hold good

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28. The speed of sound in a gas of density ρ at a pressure P is proportional to

(a) $\left(\frac{P}{\rho}\right)^2$ (b) $\left(\frac{P}{\rho}\right)^{3/2}$

(c) $\sqrt{\frac{\rho}{P}}$ (d) $\sqrt{\frac{P}{\rho}}$

29. If λ_1, λ_2, λ_3 are the wavelengths of the waves giving resonance with the fundamental, first and second overtones respectively of a closed organ pipe, then the ratio of $\lambda_1 : \lambda_2 : \lambda_3$ is

(a) 1 : 3 : 5 (b) 1 : 2 : 3

(c) 5 : 3 : 1 (d) $1 : \frac{1}{3} : \frac{1}{5}$

30. The equation of stationary wave along a stretched string is given by $y = 5\sin\frac{\pi x}{3}\cos 40\pi t$ where x and y are in cm and t in second. The separation between two adjacent nodes is

(a) 1.5 cm (b) 3 cm

(c) 6 cm (d) 4 cm

31. A uniform wire 20 m long and weighing 50 N hangs vertically. The speed of the transverse wave at the middle point of the wire is
(Take $g = 10\ \text{m s}^{-2}$)

(a) $4\ \text{m s}^{-1}$ (b) $10\sqrt{2}\ \text{m s}^{-1}$

(c) $10\ \text{m s}^{-1}$ (d) zero m s^{-1}

32. The equation of a simple harmonic wave is given by

$$y = 3\sin\frac{\pi}{2}(50t - x),$$

where x and y are in metres and t is in seconds. The ratio of maximum particle velocity to the wave velocity is

(a) 2π (b) $\frac{3}{2}\pi$

(c) 3π (d) $\frac{2}{3}\pi$

33. A train moving at a speed of 220 m s^{-1} towards a stationary object, emits a sound of frequency 1000 Hz. Some of the sound reaching the object gets reflected back to the train as echo. The frequency of the echo as detected by the driver of the train is
(Speed of sound in air is 330 m s^{-1})

(a) 3500 Hz (b) 4000 Hz

(c) 5000 Hz (d) 3000 Hz

34. An open organ pipe of length l is sounded together with another open organ pipe of length $l + x$ in their fundamental tones. Speed of sound in air is v. The beat frequency heard will be ($x \ll l$)

(a) $\frac{vx}{4l^2}$ (b) $\frac{vl^2}{2x}$

(c) $\frac{vx}{2l^2}$ (d) $\frac{vx^2}{2l}$

35. The equation for the vibration of a string fixed at both ends vibrating in its third harmonic is given by
$y = 2\ \text{cm}\ \sin[(0.6\ \text{cm}^{-1})x]\ \cos[(500\pi\ \text{s}^{-1})t]$
The length of the string is

(a) 24.6 cm (b) 12.5 cm

(c) 20.6 cm (d) 15.7 cm

36. Distance between successive compressions and rarefactions is 1 m and velocity of sound is 360 m s^{-1}. Find the frequency

(a) 180 Hz (b) 45 Hz

(c) 120 Hz (d) 90 Hz

37. Air is blown at the mouth of a tube of length 25 cm and diameter equal to 2 cm open at both ends. If velocity of sound in air is 330 m s^{-1}, the sound emitted will have all the frequencies in the group.

(a) 330, 990, 1690 Hz (b) 302, 664, 1320 Hz

(c) 660, 1320, 1980 Hz (d) 660, 100, 3300 Hz

38. When 2 tuning forks (fork 1 and fork 2) are sounded simultaneously, 4 beats s^{-1} are heard. Now, some tape is attached on the prong of fork 2. When the tuning forks are sounded again, 6 beats s^{-1} are heard if the frequency of fork 1 is 200 Hz, then what was the original frequency of fork 2?

(a) 196 Hz (b) 200 Hz

(c) 202 Hz (d) 204 Hz

39. If man were standing unsymmetrically between parallel cliffs, claps his hands and starts hearing a series of echoes at intervals of 1 s. If speed of sound in air is 340 m s^{-1}, the distance between two cliffs would be

(a) 340 m (b) 510 m

(c) 170 m (d) 680 m

40. In a resonance column Ist and 2nd resonance are obtained at length 22.7 cm and 70.2 cm. The third resonance will be obtained at a length.

(a) 117.7 cm (b) 92.9 cm

(c) 115.5 cm (d) 113.5 cm

41. A person carrying a whistle emitting continuously a note of 272 Hz is running towards a reflecting surface with a speed of 18 km hour^{-1}. The speed of sound in air is 345 m s^{-1}. The number of beats heard by him is

(a) 4 (b) 6

(c) 8 (d) 3

42. The displacement y of a wave travelling in x-direction is given by $y = 10^{-4}\sin\left(600t - 2x + \frac{\pi}{3}\right)$ where x and y are in metres and t is in second. The speed of wave motion in m s^{-1} is

(a) 300 (b) 600

(c) 1200 (d) 200

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43. An open organ pipe has fundamental frequency 100 Hz. What frequency will be produced if its one end is closed?

(a) 100, 200, 300 .... (b) 50, 150, 250....
(c) 50, 100, 200, 300 .... (d) 50, 100, 150, 200....

44. Equations of a stationary wave and a travelling wave are $y_1 = a\sin kx \cos\omega t$ and $y_2 = a\sin(\omega t - kx)$. The phase difference between two points $x_1 = \frac{\pi}{3k}$ and $x_2 = \frac{3\pi}{2k}$ are ϕ_1 and ϕ_2 respectively for the two waves. The ratio ϕ_1/ϕ_2 is

(a) 1 (b) $\frac{5}{6}$
(c) $\frac{3}{4}$ (d) $\frac{6}{7}$

45. An air column in a pipe which is closed at one end, will be in resonance with the vibrating body of frequency 166 Hz, if the length of the air column is

(a) 0.5 m (b) 1.0 m
(c) 1.5 m (d) 2.0 m

DAY 14 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____

(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (b) : Here, $\upsilon = 45$ Hz, $M = 3.5 \times 10^{-2}$ kg
Linear mass density

$$\mu = \frac{\text{mass}}{\text{length}} = 4.0 \times 10^{-2} \text{ kg m}^{-1}$$

$$\therefore \quad l = \frac{m}{\mu} = \frac{3.5 \times 10^{-2}}{4.0 \times 10^{-2}} = \frac{7}{8}$$

$$\text{As} \quad \frac{\lambda}{2} = l = \frac{7}{8} \quad \therefore \quad \lambda = \frac{7}{4} \text{ m}$$

The speed of the transverse wave is

$$v = \upsilon\lambda = 45 \times \frac{7}{4} \text{ m s}^{-1} \approx 79 \text{ m s}^{-1}$$

2. (c) : In case of open pipe, the frequency of second harmonic is,

$$\upsilon_1 = v/l$$

In case of closed pipe, the frequency of n^{th} harmonic is

$$\upsilon_2 = nv/4l = nv/4$$

Here, $n = 1, 3, 5 \ldots$. *i.e.* n is odd
If $n = 3$, $\upsilon_2 < \upsilon_1$. This is not acceptable
If $n = 5$, $\upsilon_2 = 5/4\upsilon_1$. This is acceptable.

3. (a) : According to Hooke's law,
Tension (T) $\propto$ Extension (x)
Also, speed of sound,

$$v \propto \sqrt{T} \Rightarrow v \propto \sqrt{x}$$

$$\therefore \quad \frac{v'}{v} = \sqrt{\frac{x'}{x}}$$

Here, $x' = 1.5x$

$$\therefore \quad \frac{v'}{v} = \sqrt{\frac{1.5x}{x}} = 1.22 \text{ or } v' = 1.22\, v$$

4. (a) : For a closed pipe,

$$\upsilon = n\frac{v}{4L} \text{ where } n = 1, 3, 5, \ldots$$

$$\therefore \quad \upsilon_1 = \frac{v}{4L} = \frac{320}{4 \times 1} = 80 \text{ Hz}$$

$$\upsilon_3 = 3\upsilon_1 = 240 \text{ Hz}$$
$$\upsilon_5 = 5\upsilon_1 = 400 \text{ Hz}$$

5. (a) : Given $y = 5\sin\frac{\pi}{2}(100t - x)$ ...(i)

$$y = A\sin(\omega t - kx) \quad \ldots(ii)$$

The standard equation of simple harmonic wave is

$$\therefore \quad \omega = \frac{2\pi}{T} = \frac{\pi}{2} \times 100 \text{ or } T = \frac{2}{50} = 0.04 \text{ s.}$$

6. (a) : Fundamental frequency of a closed pipe,

$$\upsilon = \frac{v}{4L}$$

First overtone of a closed pipe is equal to the third harmonic

$$= 3\upsilon = \frac{3v}{4l}$$

Again, fundamental frequency of an open pipe is

$$\upsilon' = \frac{v}{2l'}$$

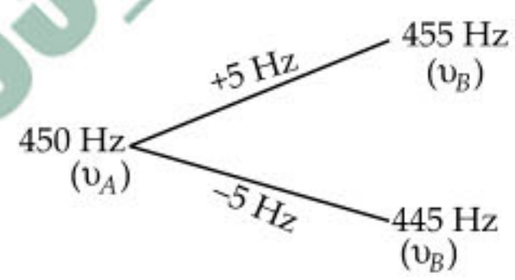
Third harmonic of open pipe $= 3\upsilon' = \frac{3v}{2l}$
According to the question,

$$\frac{3v}{4l} = \frac{3v}{2l'} \Rightarrow \frac{l}{l'} = \frac{1}{2} = 1:2$$

7. (b) : Frequency of $A = 320 \pm 4 = 324$ or 316 Hz. As frequency increases on filing, so before filing frequency of the fork $A = 316$ Hz (lower value)

8. (c) : The frequency of string A, $\upsilon_A = 450$ Hz
Let the frequency of string B be υ_B

$$\therefore \quad \upsilon_B = (\upsilon_A \pm 5) \text{ Hz} = (450 \pm 5) \text{ Hz}$$
$$= 455 \text{ Hz or } 445 \text{ Hz}$$



Increase in the tension of a string B, increases its frequency.
(i) If $\upsilon_B = 455$ Hz, a further increase in υ_B, increase the beat frequency. But this is not given in the question.
(ii) If $\upsilon_B = 445$ Hz, a further increase in υ_B decrease the beat frequency. This is given in the question.
$\therefore$ The frequency of string B be 445 Hz.

9. (b) : Here, Speed of sound, $v = 330$ m s^{-1}
Length of pipe, $L = 30$ cm $= 30 \times 10^{-2}$ m
In a open pipe (open at both ends) the frequency of its n^{th} harmonic is

$$\upsilon_n = \frac{nv}{2l} \quad \text{where } n = 1, 2, 3, \ldots\ldots$$

$$\therefore \quad n = \frac{2l\upsilon_n}{v}$$

Let n^{th} harmonic of open pipe resonate with 1.1 kHz source.

$$\therefore \quad \upsilon_n = 1.1 \text{ kHz} = 1.1 \times 10^3 \text{ Hz}$$

$$\therefore \quad n = \frac{2 \times 30 \times 10^{-2} \times 1.1 \times 10^3}{330} = 2$$

10. (c) : Here, bat is a source of sound and the wall is an observer at rest.
$\therefore$ Frequency of sound reaching the wall is

$$\upsilon' = \frac{v\upsilon}{v - v_s} \quad \ldots(i)$$

where v is the velocity of sound in air and v_s is velocity of source.
On reflection, the wall is the source of sound of frequency υ' at rest and bat is an observer approaching the wall

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∴ frequency heard by the bat is

$$\upsilon'' = \frac{\upsilon'(v+v_0)}{v} = \upsilon\left(\frac{v+v_0}{v-v_s}\right) \qquad \text{(Using (i))}$$

$$= 90\times10^3\left(\frac{330+4}{330-4}\right) = \frac{90\times10^3\times334}{326}$$

$$= 92.1\times10^3 \text{ Hz}$$

11. (d) : The equation of a given progressive wave is

$$y = 5\sin(100\pi t - 0.4\pi x) \qquad ...(i)$$

The standard equation of a progressive wave is

$$y = a\sin(\omega t - kx) \qquad ...(ii)$$

Comparing (i) and (ii), we get

$a = 5$ m, $\omega = 100\pi$ rad s^{-1}, $k = 0.4\pi$ m^{-1}

(1) Amplitude of the wave, $a = 5$ m

(2) Wavelength of the wave, $\lambda = \frac{2\pi}{k} = \frac{2\pi}{0.4\pi} = 5$ m

(3) Frequency of the wave, $\upsilon = \frac{\omega}{2\pi} = \frac{100\pi}{2\pi} = 50$ Hz

(4) Velocity of the wave, $v = \upsilon\lambda = (50 \text{ s}^{-1})\ (5 \text{ m}) = 250 \text{ m s}^{-1}$

12. (a) : Let t_1 be the time taken by the stone to strike the surface of water in the pond.

Using $h = ut + \frac{1}{2}gt^2$

$$\therefore \quad h = \frac{1}{2}gt_1^2 \qquad (\because u = 0)$$

$$\text{or} \quad t_1 = \sqrt{\frac{2h}{g}}$$

Time taken by sound to reach the top of tower,

$$t_2 = \frac{h}{v}$$

Total time after which splash of sound is heard

$$t = t_1 + t_2 = \sqrt{\frac{2h}{g}} + \frac{h}{v}$$

13. (a) : Here, $L = 20$ m, $T = 200$ N, $M = 2.5$ kg

Mass per unit length,

$$\mu = \frac{M}{L} = \frac{2.5 \text{ kg}}{20 \text{ m}} = 0.125 \text{ kg m}^{-1}$$

$$\text{Velocity, } v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{200 \text{ N}}{0.125 \text{ kg m}^{-1}}} = 40 \text{ m s}^{-1}$$

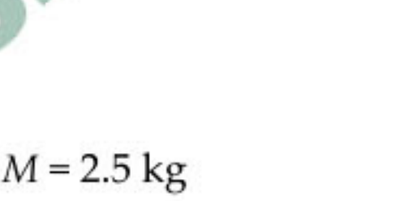
Time taken by disturbance to reach the other end,

$$t = \frac{L}{v} = \frac{20 \text{ m}}{40 \text{ m s}^{-1}} = 0.5 \text{ s}$$

14. (c) : Here, $L = 100$ cm $= 1$ m,

$v = 5$ km s^{-1} $= 5\times10^3$ m s^{-1}

As the rod is clamped at the middle, therefore the middle point is a node. In the fundamental mode, the antinode is formed at each end as shown in figure.



Therefore, the distance between two consecutive antinodes $= L = 1$ m

But the distance between two consecutive antinodes is $\frac{\lambda}{2}$.

$$\therefore \quad \frac{\lambda}{2} = 1 \text{ m} \quad \text{or} \quad \lambda = 2 \text{ m}$$

The frequency of the fundamental mode is

$$\upsilon = \frac{v}{\lambda} = \frac{5\times10^3 \text{ m s}^{-1}}{2 \text{ m}} = 2.5\times10^3 \text{ Hz} = 2.5 \text{ kHz}$$

15. (c) : Speed of sound in air is $v = \sqrt{\frac{\gamma RT}{M}}$ where T is the absolute temperature.

Since γ and M are constants

$$\therefore \quad v \propto \sqrt{T}$$

$$\Rightarrow \quad \frac{v_t}{v_0} = \sqrt{\frac{273+t}{273}}$$

$$\frac{3v_0}{v_0} = \sqrt{\frac{273+t}{273}}$$

Squaring both sides, we get

$$9 = \frac{273+t}{273} \quad \text{or} \quad 2457 = 273 + t \quad \text{or} \quad t = 2184°\text{C}$$

16. (c) : The given wave equation is

$$y = \frac{1}{10}\sin(60t + 2x)$$

Compare it with the standard wave equation

$y = A\sin(\omega t + kx)$

We get,

(i) Amplitude, $A = \frac{1}{10}$ m $= 10$ cm

(ii) Angular frequency, $\omega = 60$ rad s^{-1}

(iii) Angular wave number, $k = 2$ rad m^{-1}

$$\therefore \quad \text{Velocity of the wave, } v = \frac{\omega}{k} = \frac{60 \text{ rad s}^{-1}}{2 \text{ rad m}^{-1}} = 30 \text{ m s}^{-1}$$

$$\therefore \quad \text{Frequency of the wave, } \upsilon = \frac{\omega}{2\pi} = \frac{60}{2\pi} = \frac{30}{\pi} \text{ Hz}$$

$$\therefore \quad \text{Wavelength of the wave, } \lambda = \frac{2\pi}{k} = \frac{2\pi}{2} = \pi \text{ m}$$

As there is positive sign between t and x terms, the given wave is moving in the negative x direction.

17. (d) : The given equation is

$$y = 2\cos2\pi(10t - 0.008x + 0.35)$$

$$y = 2\cos(20\pi t - 0.016\pi x + 0.7\pi) \qquad ...(i)$$

The standard equation of travelling harmonic wave is

$$y = a\cos(\omega t - kx + \phi) \qquad ...(ii)$$

Comparing (i) and (ii), we get

$$k = 0.016\pi$$

$$\frac{2\pi}{\lambda} = 0.016\pi$$

$$\text{or} \quad \lambda = \frac{1}{0.008} \text{ cm}$$

$$\text{Phase difference} = \frac{2\pi}{\lambda} \times \text{Path difference}$$

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$$\Delta\phi = \frac{2\pi}{\lambda}\Delta x$$

When, $\Delta x = 0.5$ m $= 50$ cm

$\therefore \quad \Delta\phi = 2\pi \times 0.008 \times 50 = 0.8\pi$ rad

18. (b) : The given equation is

$$y(x, t) = 0.06 \sin\left(\frac{2\pi}{3}x\right)\cos(120\pi t)$$

Compare it with $y(x, t) = 2a\sin kx\cos\omega t$

we get

$$k = \frac{2\pi}{3} \quad \text{or} \quad \frac{2\pi}{\lambda} = \frac{2\pi}{3} \quad \text{or} \quad \lambda = 3 \text{ m}$$

and $\omega = 120\pi$ or $2\pi\upsilon = 120\pi$

or $\upsilon = 60$ Hz $= 60$ s^{-1}

Velocity of wave, $v = \upsilon\lambda = (60 \text{ s}^{-1})\ (3 \text{ m}) = 180 \text{ m s}^{-1}$

Mass per unit length of the string,

$$\mu = \frac{3\times10^{-2} \text{ kg}}{1.5 \text{ m}} = 2\times10^{-2} \text{ kg m}^{-1}$$

Velocity of transverse wave in the string,

$$v = \sqrt{\frac{T}{\mu}} \quad \text{or} \quad v^2 = \frac{T}{\mu} \quad \text{or} \quad T = v^2\mu$$

$$T = (180 \text{ m s}^{-1})^2\ (2 \times 10^{-2} \text{ kg m}^{-1}) = 648 \text{ N}$$

19. (c)

20. (b) : When the string vibrates in loops n, its frequency is

$$\upsilon_n = \frac{nv}{2L}$$

where L is the length of the string and v is the velocity of the wave.

$\therefore$ When the string fixed at its both ends vibrates in 1 loop, 2 loops, 3 loops and 4 loops, the frequencies are in the ratio 1 : 2 : 3 : 4.

21. (b) : Here, speed of sound, $v = 340 \text{ m s}^{-1}$

Length of pipe, $L = 17$ cm $= 17 \times 10^{-2}$ m

In a closed pipe (open at one end), the frequency of its n^{th} harmonic is

$$\upsilon_n = \frac{nv}{4L} \text{ where } n = 1, 3, 5, 7, \ldots.$$

Let n^{th} harmonic of closed pipe resonates with 1.5 kHz source.

$\therefore \quad \upsilon_n = 1.5 \times 10^3$ Hz

$\therefore \quad 1.5 \times 10^3 = \frac{nv}{4L}$

$$n = \frac{1.5\times10^3\times4\times17\times10^{-2}}{340} = 3$$

22. (c) : Wavelength of sound wave in the first medium,

$$\lambda = \frac{v}{\upsilon} \qquad \ldots(i)$$

Wavelength of sound wave in the second medium

$$\lambda' = \frac{2v}{\upsilon'} \qquad \ldots(ii)$$

As the frequency of the wave remains unchanged with the change in medium

$\therefore \quad \upsilon = \upsilon'$ ...(iii)

Divide (ii) by (i), we get

$$\frac{\lambda'}{\lambda} = 2 \qquad \text{[Using (iii)]}$$

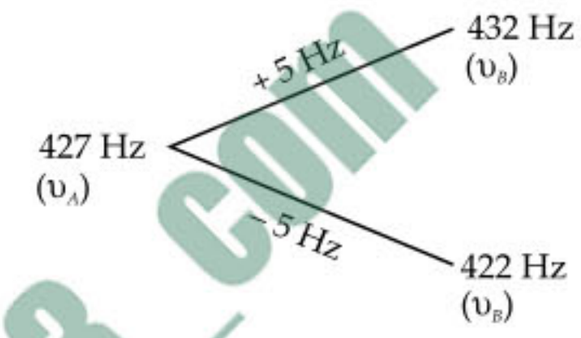
or $\lambda' = 2\lambda$

23. (a) : The frequency of string A, $\upsilon_A = 427$ Hz

Let original frequency of string B be υ_B.

$\therefore \quad \upsilon_B = (\upsilon_A \pm 5)$ Hz $= (427 \pm 5)$ Hz

$= 432$ Hz or 422 Hz



Increase in the tension of a string B, increase its frequency ($\upsilon \propto \sqrt{T}$)

(i) If $\upsilon_B = 432$ Hz, a further increase in υ_B, increase the beat frequency. But this is not given in the question.

(ii) If $\upsilon_B = 422$ Hz, a further increase in υ_B, decrease the beat frequency. This is given in the question.

$\therefore$ The original frequency of string B be 422 Hz.

24. (a) : rms speed of gas molecules is

$$v_{rms} = \sqrt{\frac{3P}{\rho}} \qquad \ldots(i)$$

Speed of sound in the gas is

$$v = \sqrt{\frac{\gamma P}{\rho}} \qquad \ldots(ii)$$

Divide (i) by (ii), we get $\frac{v_{rms}}{v} = \sqrt{\frac{3}{\gamma}}$

25. (b) : For open organ pipe, frequency of first harmonic,

$$\upsilon = \frac{v}{2L} = 480 \text{ Hz}$$

For a pipe closed at one end, frequency of first harmonic,

$$\upsilon' = \frac{v}{4L'} = 480 \text{ Hz}$$

$\therefore \quad 4L' = 2L$ or $L' = \frac{2L}{4} = \frac{L}{2}$

26. (d) : For a closed organ pipe, the frequency of fundamental mode is

$$\upsilon_C = \frac{v}{4l_C}$$

where v is the velocity of sound in air and l_C is the length of the closed pipe

For an open organ pipe, the frequency of fundamental mode is

$$\upsilon_O = \frac{v}{2l_O}$$

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where l_O is the length of the open pipe

$\because \quad l_C = l_O$ (Given)

$\therefore \quad \upsilon_O = 2\upsilon_C$ ...(i)

$\upsilon_O - \upsilon_C = 2$ (Given) ...(ii)

Solving (i) and (ii), we get

$\upsilon_O = 4$ Hz, $\upsilon_C = 2$ Hz

When the length of the open pipe is halved, its frequency of fundamental mode is

$$\upsilon'_O = \frac{v}{2\left(\frac{l_O}{2}\right)} = 2\upsilon_O = 2\times 4 \text{ Hz} = 8 \text{ Hz}$$

When the length of the closed pipe is doubled, its frequency of fundamental mode is

$$\upsilon'_C = \frac{v}{4(2l_C)} = \frac{1}{2}\upsilon_C = \frac{1}{2}\times 2 \text{ Hz} = 1 \text{ Hz}$$

Hence, number of beats produced per second

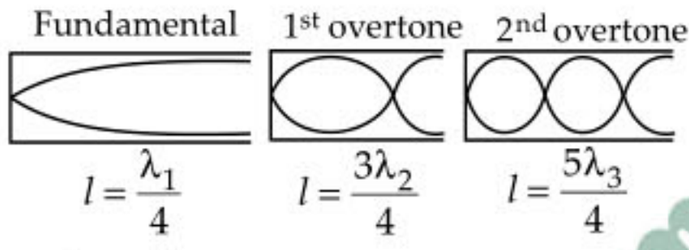
$= \upsilon'_O - \upsilon'_C = 8 - 1 = 7$ Hz

27. (c)

28. (d) : The speed of sound in a gas of density ρ at pressure P is

$$v = \sqrt{\frac{\gamma P}{\rho}}$$

29 (d) :



As it is clear from figure

$l = \frac{\lambda_1}{4}$ or $\lambda_1 = 4l$

$l = \frac{3\lambda_2}{4}$ or $\lambda_2 = \frac{4l}{3}$

$l = \frac{5\lambda_3}{4}$ or $\lambda_3 = \frac{4l}{5}$ $\therefore \quad \lambda_1 : \lambda_2 : \lambda_3 = 1 : \frac{1}{3} : \frac{1}{5}$

30. (b) : The given equation of stationary wave is

$$y = 5\sin\frac{\pi x}{3}\cos 40\pi t$$

Comparing with the standard equation of stationary wave

$y = A\sin kx\cos\omega t$

We get, $k = \frac{\pi}{3} = \frac{2\pi}{\lambda}$ or $\lambda = 6$ cm

Hence, the separation between two adjacent nodes,

$= \frac{\lambda}{2} = 3$ cm

31. (c) : Since, $v = \sqrt{\frac{T}{\mu}}$

Here, Weight of wire = 50 N

Mass of wire $= \frac{50}{10} = 5$ kg

Length of the wire = 20 m.

mass per unit length of wire.

$\therefore \quad m = (5/20) = 0.25$ kg m^{-1}

At the middle point $T = 25$ N

$$\therefore \quad v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{25}{0.25}} = \sqrt{100} = 10 \text{ m s}^{-1}$$

32. (b) : The given wave equation is $y = 3\sin\frac{\pi}{2}(50t - x)$

$$y = 3\sin\left(25\pi t - \frac{\pi}{2}x\right) \quad ...(i)$$

The standard wave equation is

$y = A\sin(\omega t - kx)$ ...(ii)

Comparing (i) and (ii), we get

$\omega = 25\pi, \ k = \frac{\pi}{2}$

Wave velocity,

$$v = \frac{\omega}{k} = \frac{25\pi}{(\pi/2)} = 50 \text{ m s}^{-1}$$

Particle velocity, $v_p = \frac{dy}{dt} = \frac{d}{dt}\left(3\sin\left(25\pi t - \frac{\pi}{2}x\right)\right)$

$$= 75\pi\cos\left(25\pi t - \frac{\pi}{2}x\right)$$

Maximum particle velocity, $(v_p)_{max} = 75\pi$ m s^{-1}

$$\therefore \quad \frac{(v_p)_{max}}{v} = \frac{75\pi}{50} = \frac{3}{2}\pi$$

33. (c) : Here, Speed of the train, $v_T = 220$ m s^{-1}

Speed of sound in air, $v = 330$ m s^{-1}

The frequency of the echo detected by the driver of the train is

$$\upsilon' = \upsilon\left(\frac{v + v_T}{v - v_T}\right) = 1000\left(\frac{330 + 220}{330 - 220}\right) = 1000\times\frac{550}{110} = 5000 \text{ Hz}$$

34. (c) : Here, $\upsilon_1 = \frac{v}{2l}$ and $\upsilon_2 = \frac{v}{2(l + x)}$

As beat frequency $\upsilon = \upsilon_1 - \upsilon_2$

$$\therefore \quad \upsilon = \frac{v}{2l} - \frac{v}{2(l + x)} = \frac{v}{2l}\left[1 - \left(1 + \frac{x}{l}\right)^{-1}\right]$$

$$= \frac{v}{2l}\left[1 - \left(1 - \frac{x}{l}\right)\right] = \frac{vx}{2l^2}$$

35. (d) : Wave number $k = \frac{2\pi}{\lambda} = 0.6$ cm^{-1}

$$\therefore \quad \frac{\lambda}{2} = \frac{\pi}{0.6} \text{ cm}$$

In third harmonic the length of the string

$$\therefore \quad l = \frac{3\lambda}{2} = 3\left(\frac{\pi}{0.6}\right) \text{ cm} = 15.7 \text{ cm}$$

36. (a) : Distance between successive compressions and rarefactions is λ/2.

or $1 = \frac{\lambda}{2}$ or $\lambda = 2$ m

Frequency $(\upsilon) = \frac{v_s}{\lambda}$

where v_s is the velocity of sound

$$\therefore \quad \upsilon = \frac{360 \text{ ms}^{-1}}{2 \text{ m}} = 180 \text{ Hz}$$

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37. (c) : As fundamental frequency of open pipe

$\therefore \quad \upsilon = \frac{v}{2l} = \frac{330}{2\times 0.25} = 660$ Hz

$\therefore$ Frequencies of overtones are $2\upsilon, 3\upsilon, 4\upsilon, \ldots = 1320, 1980, 2640$ Hz.

38. (a) : Here $\upsilon_1 = 200$ Hz.

Number of beats s^{-1}; $m = 4$

$\therefore \quad \upsilon_2 = 200 \pm 4 = 204$ or 196 Hz

On loading fork 2, its frequency decreases. And number of beats s^{-1} increases to 6. Therefore m is negative.

$\therefore \quad \upsilon_2 = 200 - 4 = 196$ Hz

39. (b) : Let x be distance of person from 1st cliff and y be distance of person from 2nd cliff. Let $y > x$.

$\therefore \quad x + x = v \times t_1 = 340 \times 1 = 340$

$\Rightarrow \quad x = 170$ m

Again $y + y = v \times t_2 = 340 \times 2 = 680$

$\Rightarrow \quad y = 340$ m

$\therefore$ The distance between two cliffs

$= x + y = 170 + 340 = 510$ m

40. (a)

41. (c) : Original frequency of whistle, $\upsilon = 272$ Hz

Apparent frequency of whistle striking the wall (listener)when person(source) is moving towards the wall with velocity $v_s = 18$ km $h^{-1} = 5$ m s^{-1} is

$$\upsilon' = \frac{v}{v - v_s} \times \upsilon = \frac{345}{345 - 5} \times 272 \quad \ldots(i)$$

On reflection, wall acts as source and person is the listener moving towards the source. Therefore,

$$\upsilon'' = \frac{v + v_L}{v} \times \upsilon' = \frac{(345+5)}{345} \times \frac{345}{340} \times 272 = 280$$

$\therefore \quad$ No. of beats per second $= \upsilon'' - \upsilon = 280 - 272 = 8$

42. (a) : Here, $y = 10^{-4} \sin\left(600t - 2x + \frac{\pi}{3}\right)$

Compare it with the standard equation of a travelling wave

$$y = A\sin\left[\frac{2\pi t}{T} - \frac{2\pi x}{\lambda} + \phi\right]$$

$$\frac{2\pi}{T} = 600, T = \frac{2\pi}{600} = \frac{\pi}{300}\text{s}$$

$$\frac{2\pi}{\lambda} = +2, \ \lambda = \frac{2\pi}{2} = \pi \text{ m}$$

$$v = \frac{\lambda}{T} = \frac{\pi}{\pi/300} = 300 \text{ m s}^{-1}$$

43. (b) : When one end is closed, $n_1 = \frac{100}{2} = 50$ Hz

44. (d) : Equation of a stationary wave is

$y_1 = a\sin kx \cos\omega t$

and equation of progressive wave is

$y_2 = a\sin(\omega t - kx) = a(\sin\omega t \cos kx - \cos\omega t \sin kx)$

At $x_1 = \frac{\pi}{3k}$ and $x_2 = \frac{3\pi}{2k}$

$\sin kx_1$ or $\sin kx_2$ is zero.

$\therefore \quad$ neither x_1 nor x_2 is node.

$$\Delta x = x_2 - x_1 = \frac{3\pi}{2k} - \frac{\pi}{3k} = \frac{7\pi}{6k}$$

As $\Delta x = \frac{7\pi}{6k}$, therefore, $\frac{2\pi}{k} > \Delta x > \frac{\pi}{k}$ But $\frac{2\pi}{k} = \lambda$.

So, $\lambda > \Delta x > \frac{\lambda}{2}$.

In case of a stationary wave, phase difference between any two points is either zero or π.

$\therefore \quad \phi_1 = \pi$ and $\phi_2 = k\Delta x = k\frac{7\pi}{6k} = \frac{7}{6}\pi$

$\therefore \quad \frac{\phi_1}{\phi_2} = \frac{\pi}{\frac{7}{6}\pi} = \frac{6}{7}$

45. (a) : When air is blown at the open end of a closed pipe a longitudinal wave travels in the air of the pipe from closed end to open end. When l is wavelength and l is the length of pipe and υ is the frequency of note emitted and v is the velocity of sound in air, then

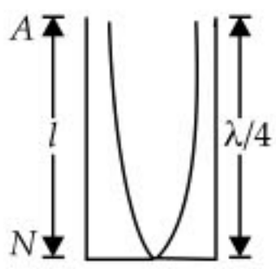
$\upsilon = \frac{v}{\lambda}$, (fundamental note)

Given, $\upsilon = 166$ Hz, $v = 332$ m s^{-1}

$\therefore \quad \lambda = \frac{332}{166} = 2$ m

But, $\lambda = 4l$

$\therefore \quad l = \frac{\lambda}{4} = \frac{2}{4} = 0.5$ m



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Unit Test 2

- Mechanical Properties of Solids
- Mechanical Properties of Fluids
- Thermal Properties of Matter • Thermodynamics
- Kinetic Theory • Oscillations • Waves

Unit test is complementary part of the learning process. It gives you a total insight whether the learning outcomes have been achieved or not. After doing daywise preparation, attempt these questions in exam like environment. This will assist you in finding particular area of weakness to work upon. An OMR sheet is given at the end to fill the correct answers.

All the Best!

Max. Marks : 180 **Time : 45 min.**

1. A steel wire of length 20 cm and uniform cross-section 1 mm^2 is tied rigidly at both the ends. The temperature of the wire is altered from 40°C to 20°C. Coefficient of linear expansion of steel is $\alpha = 1.1 \times 10^{-5}\ °C^{-1}$ and Y for steel is $2.0 \times 10^{11}\ N\ m^{-2}$, the tension in the wire is

(a) 2.2×10^6 N (b) 16 N
(c) 8×10^6 N (d) 44 N

2. A cylindrical vessel is filled with equal amounts by weights of mercury and water. The total height of the two layers is 29.2 cm. The pressure of the liquid at the bottom of the vessel is (Given, specific gravity of mercury is 13.6)

(a) 8 cm of Hg (b) 6 cm of Hg
(c) 4 cm of Hg (d) 2 cm of Hg

3. At what temperature, the average kinetic energy of translatory motion of a gas molecule will be equal to that of an electron accelerated through a potentialdifference of 10 V? (Take Boltzmann constant $k = 1.38 \times 10^{-23}\ J\ K^{-1}$)

(a) 2.42×10^3 K (b) 7.73×10^3 K
(c) 2.42×10^4 K (d) 7.73×10^4 K

4. A bottle weighing 220 g and of area of cross-section 50 cm^2 and height 4 cm oscillates on the surface of water in vertical position. Its frequency of oscillation is

(a) 1.5 Hz (b) 2.5 Hz
(c) 3.5 Hz (d) 4.5 Hz

5. A string of density 7.5 g cm^{-3} and area of cross-section 0.2 mm^2 is stretched under a tension of 20 N. When it is plucked at the midpoint, the speed of the transverse wave on the wire is

(a) 116 m s^{-1} (b) 40 m s^{-1}
(c) 200 m s^{-1} (d) 80 m s^{-1}

6. A body takes 10 minutes to cool from 60°C to 50°C. If the temperature of surroundings is 25°C, then temperature of body after next 10 minutes will be

(a) 48°C (b) 46°C
(c) 40°C (d) 42.85°C

7. When a gas filled in a closed vessel is heated through 1°C, its pressure increases by 0.4%. The initial temperature of the gas was

(a) 250 K (b) 2500 K
(c) 250°C (d) 25°C

8. In a capillary tube experiment, a vertical 30 cm long capillary tube is dipped in water. The water rises upto a height of 10 cm due to capillary action. If the experiment is conducted in a freely falling elevator, the length of the water column becomes

(a) 10 cm (b) 20 cm
(c) 30 cm (d) zero

9. Water from a tap (at the end of a horizontal pipe) emerges vertically downwards with an initial speed of 1 m s^{-1}. The cross-sectional area of the tap is $10^{-4}\ m^2$. Assume that the pressure is constant throughout the stream of water and the flow is steady. The cross-sectional area of the stream 0.15 m below the tap is

(a) $5 \times 10^{-4}\ m^2$ (b) $1 \times 10^{-5}\ m^2$
(c) $5 \times 10^{-5}\ m^2$ (d) $2 \times 10^{-5}\ m^2$

10. If an average person jogs, he produces 14.5×10^3 cal per minute. This is removed by the evaporation of sweat. The amount of sweat evaporated per minute (assuming 1 kg requires 580×10^3 cal for evaporation) is

(a) 0.025 kg (b) 2.25 kg
(c) 0.05 kg (d) 0.20 kg

11. An open pipe is suddenly closed at one end with the result that the frequency of third harmonic of the closed pipe is found to be higher by 100 Hz than fundamental frequency of the open pipe. The fundamental frequency of the open pipe is

(a) 200 Hz (b) 300 Hz
(c) 240 Hz (d) 480 Hz

12. Water rises to a height of 10 cm in a capillary tube and mercury falls to a depth of 3.42 cm in the same capillary tube. If the density of mercury is 13.6 g cm^{-3} and the angle of contact of mercury and water are 135° and 0° respectively, the ratio of surface tension of water and mercury is

(a) 1 : 0.15 (b) 1 : 3
(c) 1 : 6.5 (d) 1.5 : 1

13. The particle executes simple harmonic motion with a time period of 16 s. At time $t = 2$ s, the particle crosses the mean position while at $t = 4$ s, its velocity is 4 m s^{-1}. The amplitude of motion in m is

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(a) $\sqrt{2}\pi$ (b) $16\sqrt{2}\pi$

(c) $24\sqrt{2}\pi$ (d) $\frac{32\sqrt{2}}{\pi}$

14. Two SHMs are represented by the equations : $y_1 = 0.1\sin(100\pi t + \pi/3)$ and $y_2 = 0.1\cos\pi t$. The initial phase difference of the velocity of particle-1 with respect to the velocity of particle-2 is

(a) $\pi/6$ (b) $-\pi/4$

(c) $\pi/3$ (d) $-\pi/6$

15. If a ball of steel (density $\rho = 7.8$ g cm^{-3}) attains a terminal velocity of 10 cm s^{-1} when falling in a tank of water (coefficient of viscosity, $\eta_{water} = 8.5 \times 10^{-4}$ Pa s), then its terminal velocity in glycerine ($\rho = 1.2$ g cm^{-3}, $\eta = 13.2$ Pa s) would be nearly

(a) 6.45×10^{-4} cm s^{-1} (b) 1.5×10^{-5} cm s^{-1}

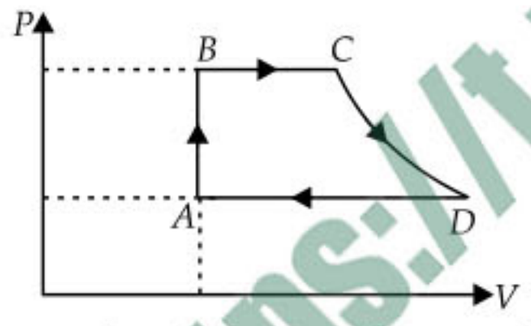
(c) 1.6×10^{-5} cm s^{-1} (d) 6.25×10^{-4} cm s^{-1}

16. The equation of motion of a particle executing simple harmonic motion is $a + 16\pi^2 x = 0$. In this equation, a is the linear acceleration in m s^{-2} of the particle at a displacement x in metre. The time period of the simple harmonic motion is

(a) $\frac{1}{4}$ s (b) $\frac{1}{2}$ s

(c) 1 s (d) 2 s

17. A cycle followed by an engine (made of one mole of an ideal gas in a cylinder with a piston) is shown in figure.



The heat exchanged by the engine with the surroundings at constant volume is (Take $C_V = \frac{3}{2}R$)

(a) $(P_B - P_A)V_A$ (b) $\frac{1}{2}(P_B - P_A)V_A$

(c) $\frac{3}{2}(P_B - P_A)V_A$ (d) $\frac{5}{2}(P_B - P_A)V_A$

18. There are 26 tuning forks arranged in the decreasing order of their frequencies. Each tuning fork gives 3 beats with the next. The first one is octave of the last. What is the frequency of 18th tuning fork?

(a) 100 Hz (b) 99 Hz

(c) 96 Hz (d) 103 Hz

19. A hole is drilled in a copper sheet. The diameter of the hole is 4.24 cm at 27°C. What is the change in the diameter of the hole when the sheet is heated to 227°C? (Take coefficient of linear expansion of copper = 1.70×10^{-5} °C^{-1})

(a) 1.44×10^{-2} cm (b) 1.44×10^{-3} cm

(c) 1.44×10^{-1} cm (d) 1.44 cm

20. A glass tube of length 1.0 m is completely filled with water. A vibrating tuning fork of frequency 500 Hz is kept over the mouth of the tube and the water is drained out slowly at the bottom of the tube. If velocity of sound in air is 330 m s^{-1}, then the total number of resonances that occur will be

(a) 2 (b) 3

(c) 1 (d) 5

21. The efficiency of Carnot engine is 50% and temperature of sink is 500 K. If temperature of source is kept constant and its efficiency raised to 60%, then the required temperature of sink will be

(a) 100 K (b) 600 K

(c) 400 K (d) 500 K

22. A copper block of mass 2.5 kg is heated in a furnace to a temperature of 500°C and then placed on a large ice block. What is the maximum amount of ice that can melt? (Take specific heat of copper = 0.39 J g^{-1} K^{-1}, heat of fusion of water = 335 J g^{-1})

(a) 1.5 kg (b) 2.5 kg

(c) 3.5 kg (d) 4.5 kg

23. A string of mass 2.5 kg is under a tension of 200 N. The length of the stretched string is 20 m. If the transverse jerk is struck at one end of the string, how long does the disturbance take to reach the other end?

(a) 1 s (b) 0.5 s

(c) 1.5 s (d) 2.5 s

24. Two simple pendulums of length 0.5 m and 20 m respectively are given small linear displacement in one direction at the same time. They will again be in the phase when the pendulum of shorter length has completed

(a) 5 oscillations (b) 1 oscillation

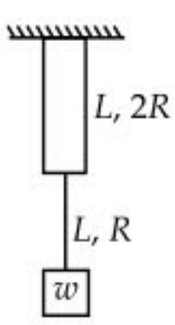
(c) 2 oscillations (d) 3 oscillations

25. The frequency of a tuning fork A is 2% more than the frequency of a standard tuning fork. The frequency of another tuning fork B is 3% less than the same standard tuning fork. If 6 beats s^{-1} are heard when the two tuning forks A and B are excited, the frequency of A is

(a) 120 Hz (b) 122.4 Hz

(c) 116.4 Hz (d) 130 Hz

26. Two wires of the same material (Young's modulus Y) and same length L but radii R and $2R$ respectively are joined end to end. A weight w is suspended from the combination as shown in the figure. The elastic potential energy in the system is



(a) $\frac{3w^2L}{4\pi R^2Y}$ (b) $\frac{3w^2L}{8\pi R^2Y}$

(c) $\frac{5w^2L}{8\pi R^2Y}$ (d) $\frac{w^2L}{\pi R^2Y}$

27. 22 g of carbon dioxide at 27°C is mixed in a closed container with 16 g of oxygen at 37°C. If both gases

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are considered as ideal gases, then the temperature of the mixture is

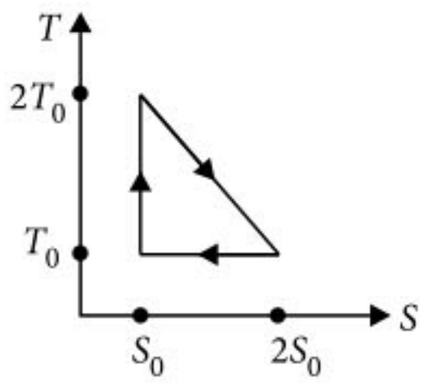
(a) 24.2°C (b) 28.5°C
(c) 31.5°C (d) 33.5°C

28. For a monoatomic gas, work done at constant pressure is W. The heat supplied at constant volume for the same rise in temperature of the gas is

(a) $W/2$ (b) $3W/2$
(c) $5W/2$ (d) W

29. The temperature-entropy diagram of a reversible engine cycle is given in figure. Its efficiency is

(a) $\frac{2}{3}$
(b) $\frac{1}{3}$
(c) $\frac{1}{4}$
(d) $\frac{1}{2}$



30. A cylinder of radius r and thermal conductivity K_1 is surrounded by a cylindrical shell of inner radius r and outer radius $2r$, whose thermal conductivity is K_2. There is no loss of heat across cylindrical surfaces, when the ends of the combined system are maintained at temperatures T_1 and T_2. The effective thermal conductivity of the system, in the steady state is

(a) $\frac{K_1K_2}{K_1+K_2}$ (b) K_1+K_2
(c) $\frac{K_1+3K_2}{4}$ (d) $\frac{3K_1+K_2}{4}$

31. Two moles of monoatomic gas is mixed with three moles of a diatomic gas. The molar specific heat of the mixture at constant volume is

(a) 1.55 R (b) 2.10 R
(c) 1.63 R (d) 2.20 R

32. A stone is hung in air from a wire which is stretched over a sonometer. The bridges of the sonometer are 40 cm apart when the wire is in unison with a tuning fork of frequency 256 Hz. When the stone is completely immersed in water, the length between the bridges is 22 cm for re-establishing unison. The specific gravity of the material of the stone is

(a) $\frac{(40)^2}{(40)^2+(22)^2}$ (b) $\frac{(40)^2}{(40)^2-(22)^2}$
(c) $256\times\frac{22}{40}$ (d) $256\times\frac{40}{22}$

33. A metallic wire with tension T and at temperature 30°C vibrates with its fundamental frequency of 1 kHz. The same wire with the same tension but at 10°C temperature vibrates with a fundamental frequency of 1.001 kHz. The coefficient of linear expansion of the wire is

(a) $2\times10^{-4}°C^{-1}$ (b) $1.5\times10^{-4}°C^{-1}$
(c) $1\times10^{-4}°C^{-1}$ (d) $0.5\times10^{-4}°C^{-1}$

34. The Poisson's ratio of a material is 0.5. If a force is applied to a wire of this material, there is a decrease in the cross-sectional area by 4%. The percentage increase in its length is

(a) 1% (b) 2%
(c) 2.5% (d) 4%

35. A simple pendulum with length L and mass m of the bob is vibrating with an amplitude a. Then the maximum tension in the string is

(a) mg (b) $mg\left[1+\left(\frac{a}{L}\right)^2\right]$
(c) $mg\left[1+\frac{a}{2L}\right]^2$ (d) $mg\left[1+\left(\frac{a}{L}\right)\right]^2$

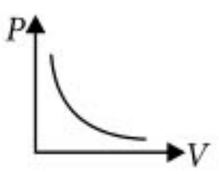
36. Two rain drops reach the earth with different terminal velocities having ratio 9 : 4. Then the ratio of their volume is

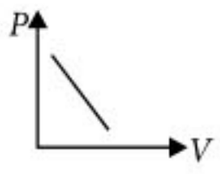
(a) 3 : 2 (b) 4 : 9
(c) 9 : 4 (d) 27 : 8

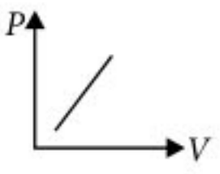
37. A pendulum consists of a wooden bob of mass m and length l. A bullet of mass m_1 is fired towards the pendulum with a speed v_1. The bullet emerges out of the bob with a speed $v_1/3$, and the bob just completes the vertical circle. The value of v_1 is

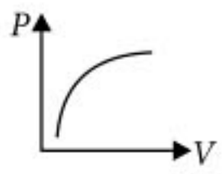
(a) $\left(\frac{m}{m_1}\right)\sqrt{5gl}$ (b) $\frac{m}{m_1}\sqrt{\frac{g}{l}}$
(c) $\frac{2}{3}\left(\frac{m_1}{m}\right)\sqrt{5gl}$ (d) $\frac{3}{2}\left(\frac{m}{m_1}\right)\sqrt{5gl}$

38. Which of the following graph best represents the variation of pressure P with volume V of a gas at fixed temperature?

(a) 

(b) 

(c) 

(d) 

39. Two identical rooms in a house are connected by an open doorway. The temperatures in the two rooms are maintained at different values. Which room contains more air?

(a) The room with higher temperature.
(b) The room with lower temperature.
(c) The room with higher pressure.
(d) Same, as both have the same pressure and volume.

40. A source of sound of frequency 500 Hz is moving towards a stationary observer with velocity 30 m s^{-1}. The speed of sound is 330 m s^{-1}. The frequency heard by the observer will be

(a) 545 Hz (b) 580 Hz
(c) 488 Hz (d) 550 Hz

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41. The objects coloured black, grey and white can withstand hostile conditions upto 2800°C. These objects are thrown into a furnace where each of them attains a temperature of 2000°C. Which object will glow the brightest?
(a) The white object
(b) The black object
(c) Grey object
(d) All glow with equal brightness

42. A pendulum is undergoing SHM with frequency f. What is the frequency of its kinetic energy?
(a) $f/2$ (b) $2f$
(c) $3f$ (d) $4f$

43. A perfect gas is found to obey the relation $PV^{3/2}$ = constant during an adiabatic process. If such a gas is initially at a temperature T, is compressed to half of its initial volume then its final temperature will be
(a) $2T$ (b) $4T$
(c) $(2)^{1/2}T$ (d) $2(2)^{1/2}T$

44. Four identical rods are stretched by same force. Maximum extension is produced in
(a) $l = 10$ cm, $D = 1$ mm
(b) $l = 100$ cm, $D = 2$ mm
(c) $l = 200$ cm, $D = 3$ mm
(d) $l = 300$ cm, $D = 4$ mm

45. In heat engine sink is fitted at temperature 27°C and heat of 100 kcal is taken from source at temperature 677°C. Work done in 10^6 J is
(a) 0.28 (b) 2.8
(c) 28 (d) 0.028

UNIT TEST 2 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____
(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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Electric Charges and Fields

Electric Charge

Charge is the physical property of certain fundamental particles (like electron, proton) by virtue of which they interact with the other similar fundamental particles. To distinguish the nature of interaction, charges are divided into two parts : (i) positive and (ii) negative. Like charges repel each other while unlike charges attract.

Conservation of charge

Charge is conserved, *i.e.* total charge on an isolated system is constant. Isolated system means a system through the boundary of which no charge is allowed to either escape or enter. This does not require that the amount of positive and negative charges be separately conserved, only their algebraic sum is conserved.

Unit of Charge

The SI unit of charge is coulomb (C).

In electrostatic CGS system, the unit of charge is known as electrostatic unit of charge (e.s.u. of charge). It is also known as stat coulomb (stat C).

$$1\ \text{C} = 3 \times 10^9\ \text{stat C}$$

In electromagnetic CGS system, the unit of charge is known as electromagnetic unit of charge (e.m.u. of charge).

$$1\ \text{C} = \frac{1}{10}\ \text{e.m.u. of charge}$$

Coulomb's Law

It states that the electrostatic force of interaction (repulsion or attraction) between two electric charges q_1 and q_2 separated by a distance r, is directly proportional to the product of the charges and inversely proportional to the square of distance between them and acts along the straight line joining two charges.

$$i.e.,\quad F = \frac{k\, q_1 q_2}{r^2},$$

where, $k = \dfrac{1}{4\pi\varepsilon_0} = 9 \times 10^9\ \text{N m}^2\ \text{C}^{-2}$ is the proportionality constant and $\varepsilon_0 = 8.854 \times 10^{-12}\ \text{C}^2\ \text{N}^{-1}\ \text{m}^{-2}$ is permittivity of free space.

The dimensional formula of ε_0 is the $[\text{M}^{-1}\text{L}^{-3}\text{T}^4\text{A}^2]$.

Relative permittivity or dielectric constant : The relative permittivity or the dielectric constant (ε_r or K) of a medium is defined as the ratio of the permittivity ε of the medium to the permittivity ε_0 of free space.

$$i.e.,\ \varepsilon_r \text{ or } K = \frac{\varepsilon}{\varepsilon_0}$$

The Coulomb's force between two charged particles in a medium is

$$F_{\text{medium}} = \frac{1}{4\pi\varepsilon}\frac{q_1 q_2}{r^2} = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{q_1 q_2}{r^2}$$

$$F_{\text{medium}} = \frac{F_{\text{vacuum}}}{K}$$

Comparison between Coulomb force and gravitational force are as follows :

- Coulomb force and gravitational force follow the same inverse square law.
- Coulomb force can be attractive or repulsive while gravitational force is always attractive.
- Coulomb force between the two charges depends on the medium between two charges while gravitational force is independent of the medium between the two bodies.
- The ratio of coulomb force to the gravitational force between two protons at a same distance apart is

$$\frac{e^2}{4\pi\varepsilon_0 G m_p m_p} = 1.3 \times 10^{36}$$

Superposition Principle

According to this principle, if charge Q is acted upon by several charges $q_1, q_2 \ldots\ldots q_n$, then the net force on Q can be found out by calculating separately the forces $F_1, F_2 \ldots\ldots, F_n$ exerted by $q_1, q_2 \ldots\ldots q_n$ respectively, on Q and then adding these forces vectorially. Their resultant, F is the total force on Q due to the collection of charges. Thus, the net force on a charge Q is the vector sum of forces on Q due to all the remaining charges.

Continuous charge distributions

Linear charge density : Charge per unit length is known as linear charge density. It is denoted by symbol λ.

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$$\lambda = \frac{\text{Charge}}{\text{Length}}$$

Its SI unit is C m^{-1}.

Surface charge density : Charge per unit area is known as surface charge density. It is denoted by symbol σ.

$$\sigma = \frac{\text{Charge}}{\text{Area}}$$

Its SI unit is C m^{-2}.

Volume charge density : Charge per unit volume is known as volume charge density. It is denoted by symbol ρ.

$$\rho = \frac{\text{Charge}}{\text{Volume}}$$

Its SI unit is C m^{-3}.

Electric Field

It is that space in which a charged particle experiences a force.

Electric field strength or electric intensity at a point in an electric field is the force per unit charge acting on a small test charge kept at that point.

$$\vec{E} = \frac{\vec{F}}{q}$$

where the test charge is always positive.

Electric intensity at a distance r from a point charge Q is given as

$$|\vec{E}| = \frac{|\vec{F}|}{q} = \frac{kQq}{qr^2}, \; |\vec{E}| = \frac{kQ}{r^2}$$

Electric field intensity $\vec{E}$ is a vector quantity. The direction of electric field is same as that of force acting on the positive test charge. The unit of E is N C^{-1} or V m^{-1} and dimensions of it is $[MLT^{-3}A^{-1}]$.

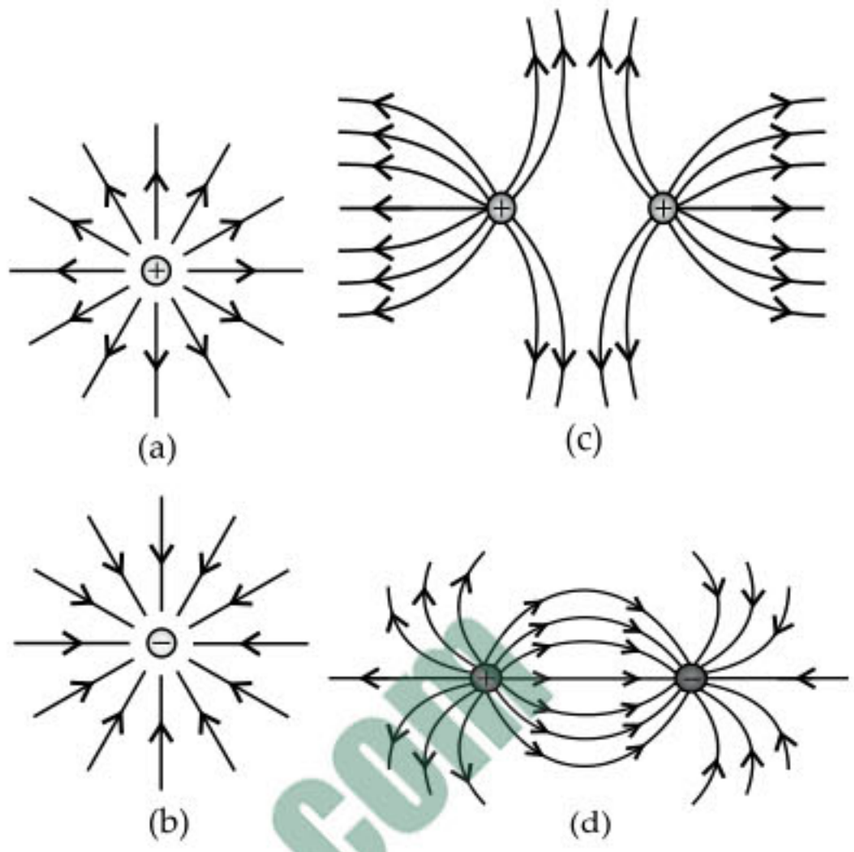
Electric Field Lines

An electric field line is a path, straight or curved such that tangent to it at any point gives the direction of electric field intensity at that point.

Properties of electric field lines

- Electric field lines start from positive charges and end at negative charges. If there is a single charge, they may start or end at infinity.
- Two electric field lines can never cross each other.
- Electric field lines do not form closed loops.
- The electric field lines are closer where the electric field is stronger and the lines spread out where the electric field is weaker. In a uniform electric field, the electric field lines are equidistant, parallel straight lines.
- Electric field lines start or end normally on the surface of a conductor.
- Electric field lines do not exist inside a conductor.

Electric field lines due to different charge configurations are as shown in the figure.



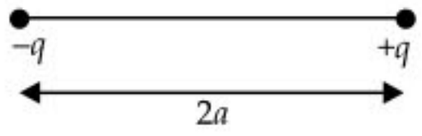
Electric Dipole

It is a combination of two equal and opposite charges kept close to each other.

Electric dipole moment

It is a vector quantity whose magnitude is equal to the product of the magnitude of charges forming the dipole and their separation.

i.e., $p = q2a$



Dipole moment is a vector directed from the negative to the positive charge.

The SI unit of electric dipole moment is C m and its dimensional formula is $[M^0LAT]$.

The practical unit of electrical dipole moment is debye.

Electric field on axial line (end on position) of an electric dipole

Electric field at a point on axial line of electric dipole is

$$E = \frac{1}{4\pi\varepsilon_0}\frac{2pr}{(r^2 - a^2)^2}$$

where r is the distance of the point from the centre of the electric dipole.

For $r >> a$,

$$E = \frac{2p}{4\pi\varepsilon_0 r^3}$$

The direction of the electric field on axial line of an electric dipole is along the direction of the dipole moment (*i.e.* from $-q$ to q).

Electric field on equatorial line (broad on position) of an electric dipole

Electric field at a point on equatorial line of electric dipole is

$$E = \frac{1}{4\pi\varepsilon_0}\frac{p}{(r^2 + a^2)^{3/2}}$$

For $r >> a$,

$$E = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}$$

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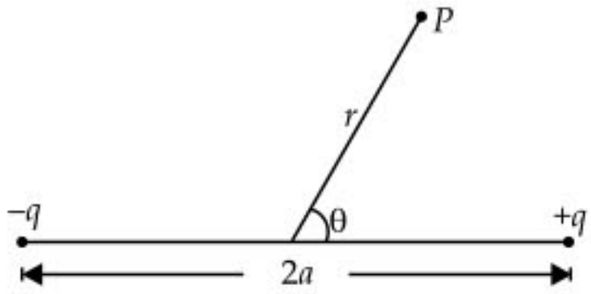
The direction of the electric field on equatorial line of the electric dipole is opposite to the direction of the dipole moment (*i.e.* from q to $-q$).

Electric field at any point due to an electric dipole



The electric field at point P due to an electric dipole is

$$E = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}\sqrt{1+3\cos^2\theta}$$

Special cases :

- When the point P lies on the axial line of dipole, *i.e.*, $\theta = 0°$

$$E = \frac{2p}{4\pi\varepsilon_0 r^3}$$

- When the point P lies on the equatorial line of dipole *i.e.* $\theta = 90°$

$$E = \frac{p}{4\pi\varepsilon_0 r^3}$$

Electric field due to a uniformly charged ring

Electric field at a point on the axis of uniformly charged ring at a distance r from its centre is

$$E = \frac{1}{4\pi\varepsilon_0}\frac{qr}{(r^2+a^2)^{3/2}}$$

where q is the charge on the ring and a is the radius of the ring.

For $r >> a$, $E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$

At the centre of the ring, $E = 0$.

Electric dipole in a uniform electric field

When an electric dipole of dipole moment $\vec{p}$ is placed in a uniform electric field $\vec{E}$, it will experience a torque and is given by

$$\vec{\tau} = \vec{p}\times\vec{E} \quad \text{or} \quad \tau = pE\sin\theta$$

where θ is the angle between $\vec{p}$ and $\vec{E}$.

Torque acting on a dipole is maximum ($\tau_{max} = pE$) when dipole is perpendicular to the field and minimum ($\tau = 0$) when dipole is parallel or antiparallel to the field.

When a dipole is placed in a uniform electric field, it will experience only torque and the net force on the dipole is zero while when it is placed in a non uniform electric field, it will experience both torque and net force.

Electric Flux

If the electric lines of force pass through a surface then the surface is said to have flux linked with it.

The flux linked with small area element on the surface of the body

$$d\phi = \vec{E}\cdot d\vec{S}$$

where $d\vec{S}$ is the area vector of the small area element. The area vector of a closed surface is always in the direction of outward normal. The total flux linked with whole of the body

$$\phi = \oint \vec{E}\cdot d\vec{S}$$

where $\oint$ is referred to closed integral done for a closed surface.

Electric flux is a scalar quantity. Its units is V m or N m^2 C^{-1} and its dimensions is $[M^1L^3T^{-3}A^{-1}]$.

Gauss's Theorem

The net electric flux emerging out of a closed surface is equal to the net charge enclosed by it divided by ε_0.

$$\oint \vec{E}\cdot d\vec{S} = \frac{\sum q_{in}}{\varepsilon_0}$$

This law is true for any closed surface, but is useful only in case of symmetry, because in other cases, the integral on the left hand side becomes very difficult to measure.

Applications of Gauss's Law

Electric field due to an infinitely long thin uniformly charged straight wire

Electric field due to thin infinitely long straight wire of uniform linear charge density λ is

$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

where r is the perpendicular distance of the observation point from the wire.

Electric field due to a uniformly charged thin spherical shell

Electric field due to uniformly charged thin spherical shell of uniform surface charge density σ and radius R at a point distant r from the centre of the shell is given as follows :

- At a point outside the shell *i.e.*, $r > R$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

- At a point on the surface of the shell *i.e.*, $r = R$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{R^2}$$

- At a point inside the shell *i.e.*, $r < R$

$$E = 0$$

Here, $q = 4\pi R^2\sigma$

The variation of E with r for a uniformly charged thin spherical shell is as shown in the figure.

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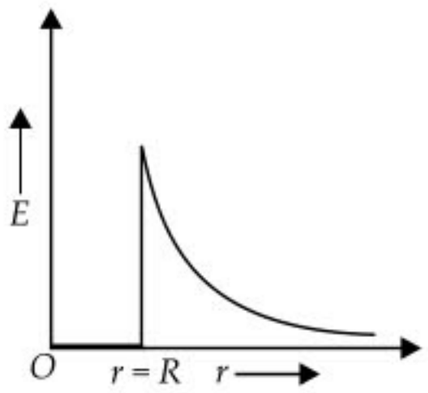


Electric field due to a uniformly charged non-conducting solid sphere

Electric field due to a uniformly charged non-conducting solid sphere of uniform volume charge density ρ and radius R at a point distant r from the centre of the sphere is given as follows :

- At a point outside the sphere *i.e.*, $r > R$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

- At a point on the surface of the sphere *i.e.*, $r = R$

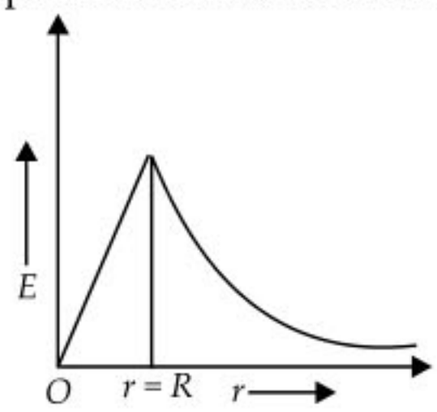
$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{R^2}$$

- At a point inside the sphere *i.e.*, $r < R$

$$E = \frac{\rho r}{3\varepsilon_0} = \frac{1}{4\pi\varepsilon_0}\frac{qr}{R^3}$$

Here, $q = \frac{4}{3}\pi R^3\rho$

The variation of E with r for a uniform charged non-conducting sphere is as shown in the figure.



Electric field due to a uniformly charged infinite thin plane sheet

Electric field due to a uniformly charged infinite thin plane sheet of surface charge density σ is

$$E = \frac{\sigma}{2\varepsilon_0}$$

E is independent of r, distance of the point from sheet.

Electric field due to two thin infinite parallel sheets of equal and opposite charges

Electric field due to two thin infinite parallel sheets of uniform surface density +σ and –σ, is given as follows :

- At a point anywhere in the space between the two sheets

$$E = \frac{\sigma}{\varepsilon_0}$$

- At point outside the sheets, $E = 0$.

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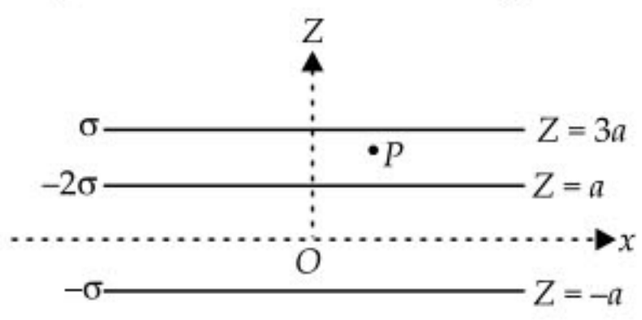
EXAM DRILL

1. Three infinitely long charge sheets are placed as shown in figure. The electric field at point P is



(a) $\frac{2\sigma}{\varepsilon_0}\hat{k}$ (b) $-\frac{2\sigma}{\varepsilon_0}\hat{k}$ (c) $\frac{4\sigma}{\varepsilon_0}\hat{k}$ (d) $-\frac{4\sigma}{\varepsilon_0}\hat{k}$

2. An electric dipole consists of two opposite charges, each of magnitude 1.0 μC separated by a distance of 2.0 cm. The dipole is placed in an external electric field of 10^5 N C^{-1}. The maximum torque on the dipole is

(a) 0.2×10^{-3} N m (b) 1×10^{-3} N m
(c) 2×10^{-3} N m (d) 4×10^{-3} N m

3. A ring of radius R carries a charge Q, uniformly distributed along its circumference. What is the ratio of the electric field strength at a distance R to that at a distance $\frac{R}{\sqrt{2}}$ along the axis?

(a) $\frac{\sqrt{3}}{8}$ (b) $\frac{3\sqrt{3}}{8}$ (c) $\frac{3\sqrt{3}}{4\sqrt{2}}$ (d) $\frac{2\sqrt{2}}{3\sqrt{3}}$

4. An infinitely long thin straight wire has uniform linear charge density of $\frac{1}{3}$ C m^{-1}. Then the magnitude of the electric intensity at a point 18 cm away is

(a) 0.33×10^{11} N C^{-1} (b) 3×10^{11} N C^{-1}
(c) 0.66×10^{11} N C^{-1} (d) 1.32×10^{11} N C^{-1}

5. Two point charges are 3 m apart and their combined charge is 8 μC. The force of repulsion between them is 0.012 N. Charges are

(a) 4 μC, 4 μC (b) 6 μC, 2 μC
(c) 5 μC, 3 μC (d) 7 μC, 1 μC

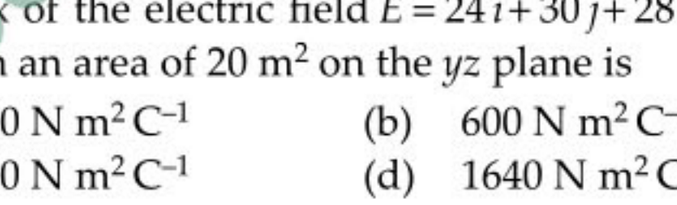
6. A charge Q is enclosed by a Gaussian spherical surface of radius R. If the radius is doubled, then the outward electric flux will

(a) increase four times (b) be reduced to half
(c) remain the same (d) be doubled

7. The direction of electric field intensity ($\vec{E}$) at a point on the equatorial line of an electric dipole of dipole moment ($\vec{p}$) is

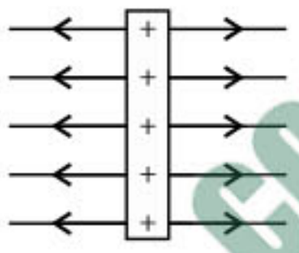
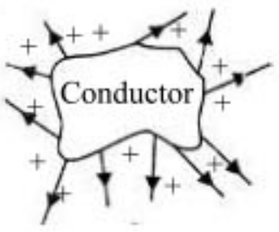
(a) along the equatorial line towards the dipole
(b) along the equatorial line away from the dipole
(c) perpendicular to the equatorial line and opposite to ($\vec{p}$)
(d) perpendicular to the equatorial line and parallel to ($\vec{p}$)

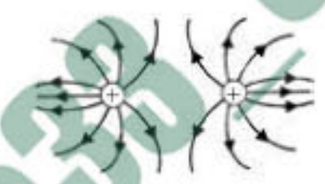
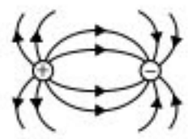
8. What is the electric flux linked with closed surface ?



(a) 10^{11} N m^2 C^{-1} (b) 10^{12} N m^2 C^{-1}
(c) 10^{10} N m^2 C^{-1} (d) 8.86×10^{13} N m^2 C^{-1}

9. Which of the following figures cannot possibly represent electrostatic field lines?

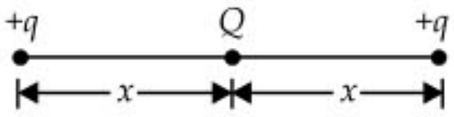
(a) 
(b) 

(c) 
(d) 

10. The flux of the electric field $\vec{E} = 24\hat{i} + 30\hat{j} + 28\hat{k}$ N C^{-1} through an area of 20 m^2 on the yz plane is

(a) 480 N m^2 C^{-1} (b) 600 N m^2 C^{-1}
(c) 560 N m^2 C^{-1} (d) 1640 N m^2 C^{-1}

11. A charge Q is placed at the centre of the line joining two point charges $+q$ and $+q$, as shown in the figure.



What is the ratio $\frac{Q}{q}$ for the system to be in equilibrium?

(a) 4 (b) $\frac{1}{4}$ (c) −4 (d) $-\frac{1}{4}$

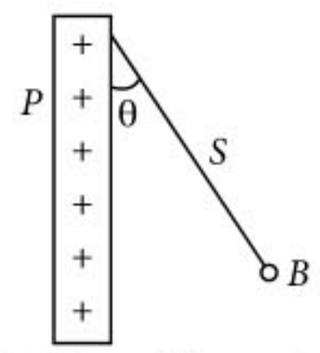
12. In a region, the intensity of an electric field is given by $\vec{E} = 2\hat{i} + 3\hat{j} + \hat{k}$ in NC^{-1}. The electric flux through a surface $\vec{S} = 10\hat{i}$ m^2 in the region is

(a) 5 Nm^{2}C^{-1} (b) 10 Nm^{2}C^{-1}
(c) 15 Nm^{2}C^{-1} (d) 20 Nm^{2}C^{-1}

13. Let $\rho(r) = \frac{Qr}{\pi R^4}$ be the charge density distribution for a solid sphere of radius R and total charge Q. For a point P inside the sphere at a distance r_1 from the centre of the sphere, the magnitude of electric field is

(a) $\frac{Q}{4\pi\varepsilon_0 r_1^2}$ (b) $\frac{Qr_1^2}{4\pi\varepsilon_0 R^4}$ (c) $\frac{Qr_1^2}{3\pi\varepsilon_0 R^4}$ (d) zero

14. A charged ball B hangs from a silk thread S, which makes an angle θ with a large charged conducting sheet P as shown in figure. The surface charge density of the sheet is proportional to



(a) cos θ (b) cot θ (c) sin θ (d) tan θ

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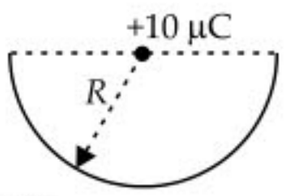
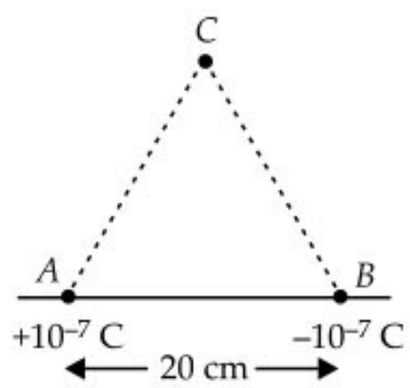
15. A charge 10 μC is placed at the centre of a hemisphere of radius R = 10 cm as shown. The electric flux through the hemisphere (in MKS units) is



(a) 20×10^5 (b) 10×10^5
(c) 6×10^5 (d) 2×10^5

16. Two point charges $+10^{-7}$ C and -10^{-7} C are placed at A and B, 20 cm apart as shown in the figure. Calculate the electric field at C, 20 cm apart from both A and B.



(a) 1.5×10^{-5} N/C
(b) 2.2×10^4 N/C
(c) 3.5×10^6 N/C (d) 3.0×10^5 N/C

17. The electric field due to an infinitely long straight uniformly charged wire at a distance r is directly proportional to

(a) r (b) r^2 (c) $\frac{1}{r}$ (d) $\frac{1}{r^2}$

18. There is a point charge q located at the centre of a cube. What is the electric flux of this point charge, through a face of the cube?

(a) $\frac{q}{\varepsilon_0}$ (b) $\frac{q}{6\varepsilon_0}$
(c) $\frac{q}{3\varepsilon_0}$
(d) It will depend upon the size of the cube.

19. An electron initially at rest falls a distance of 1.5 cm in a uniform electric field of magnitude 2×10^4 N C^{-1}. The time taken by the electron to fall this distance is

(a) 1.3×10^2 s (b) 2.1×10^{-12} s
(c) 1.6×10^{-10} s (d) 2.9×10^{-9} s

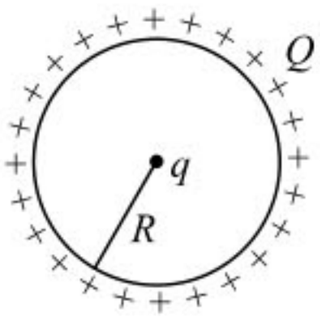
20. A conducting sphere of radius 10 cm has an unknown charge. If the electric field at a distance 20 cm from the centre of the sphere is 1.2×10^3 N C^{-1} and points radially inwards. The net charge on the sphere is

(a) -4.5×10^{-9} C (b) 4.5×10^9 C
(c) -5.3×10^{-9} C (d) 5.3×10^9 C

21. An oil drop of 10 excess electrons is held stationary under a constant electric field of 3.65×10^4 N C^{-1} in Millikan's oil drop experiment. The density of oil is 1.26 g cm^{-3}. Radius of the oil drop is
(Take, $g = 9.8$ m s^{-2}, $e = 1.6 \times 10^{-19}$ C)

(a) 1.0×10^{-6} m (b) 4.8×10^{-5} m
(c) 4.8×10^{-18} m (d) 1.13×10^{-18} m

22. A positive charge Q is uniformly distributed along a circular ring of radius R. A small test charge q is placed at the centre of the ring as shown in figure.
Then



(a) if $q > 0$ and is displaced away from the centre in the plane of the ring, it will be pushed back towards the centre.
(b) if $q < 0$ and is displaced away from the centre in the plane of the ring, it will never return to the centre and will continue moving till it hits the ring.
(c) if $q < 0$ it will perform SHM for small displacement along the axis.
(d) all of the above.

23. Under the action of a given coulombic force the acceleration of an electron is 2.5×10^{22} m s^{-2}. Then the magnitude of the acceleration of a proton under the action of same force is nearly

(a) 1.6×10^{-19} m s^{-2} (b) 9.1×10^{31} m s^{-2}
(c) 1.4×10^{19} m s^{-2} (d) 1.6×10^{27} m s^{-2}

24. A rod of length 2.4 m and radius 4.6 mm carries a negative charge of 4.2×10^{-7} C spread uniformly over its surface. The electric field near the mid-point of the rod, on its surface is

(a) -8.6×10^5 N C^{-1} (b) 8.6×10^4 N C^{-1}
(c) -6.8×10^5 N C^{-1} (d) 6.8×10^4 N C^{-1}

25. The ratio of magnitude of electrostatic force and gravitational force between an electron and a proton is

(a) 6.6×10^{39} (b) 2.3×10^{39}
(c) 6.6×10^{29} (d) 2.3×10^{29}

26. The electrostatic potential inside a charged spherical ball is given by $\phi = ar^2 + b$ where r is the distance from the centre; a, b are constants. Then the charge density inside the ball is

(a) $-24\pi a\varepsilon_0 r$ (b) $-6a\varepsilon_0 r$ (c) $-24\pi a\varepsilon_0$ (d) $-6a\varepsilon_0$

27. Electrical as well as gravitational effects can be thought to be caused by fields. Which of the following is true of an electrical or gravitational field ?

(a) The field concept is often used to describe contact forces.
(b) Gravitational or electric field does not always exist in the space around an object.
(c) Fields are useful for understanding forces acting through a distance.
(d) There is no way to verify the existence of a force field since it is just a concept.

28. If an object of mass 1 kg contains 4×10^{20} atoms. If one electron is removed from every atom of the solid, the charge gained by the solid in 1 g is

(a) 2.8 C (b) 6.4×10^{-2} C
(c) 3.6×10^{-3} C (d) 9.2×10^{-4} C

29. Two point charges of 1 μC and –1 μC are separated by a distance of 100 Å. A point P is at a distance of 10 cm from the midpoint and on the perpendicular bisector of the line joining the two charges. The electric field at P will be

(a) 9 N C^{-1} (b) 0.9 N C^{-1}
(c) 90 N C^{-1} (d) 0.09 N C^{-1}

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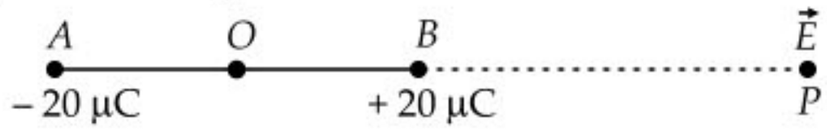
30. Two charges ± 20 μC are placed 10 mm apart. The electric field at point P, on the axis of the dipole 10 cm away from its centre O on the side of the positive charge is



(a) 8.6×10^9 N C^{-1} (b) 4.1×10^6 N C^{-1}
(c) 3.6×10^6 N C^{-1} (d) 4.6×10^5 N C^{-1}

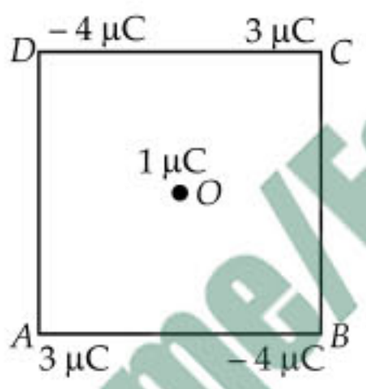
31. In a field free region, two electrons are released to move on a line towards each other with velocities 10^6 m s^{-1}. The distance of their closest approach will be nearer to

(a) 1.28×10^{-10} m (b) 1.92×10^{-10} m
(c) 2.56×10^{-10} m (d) 3.84×10^{-10} m

32. A uniform electric field $E = 2 \times 10^3$ N C^{-1} is acting along the positive x-axis. The flux of this field through a square of 10 cm side whose plane is parallel to the yz plane is

(a) 20 N C^{-1} m^2 (b) 30 N C^{-1} m^2
(c) 10 N C^{-1} m^2 (d) 40 N C^{-1} m^2

33. Four point charges are placed at the corners of a square $ABCD$ of side 10 cm, as shown in figure. The force on a charge of 1 μC placed at the centre of square is



(a) 7 N
(b) 8 N
(c) 2 N
(d) zero

34. If there were only one type of charge in the universe, then

(a) $\oint_s \vec{E} \cdot \overrightarrow{ds} \neq 0$ on any surface

(b) $\oint_s \vec{E} \cdot \overrightarrow{ds} = 0$ if the charge is outside the surface

(c) $\oint_s \vec{E} \cdot \overrightarrow{ds} = \frac{q}{\varepsilon_0}$ if charges of magnitude q were inside the surface

(d) both (b) and (c) are correct

35. A uniformly charged conducting sphere of 4.4 m diameter has a surface charge density of 60 μC m^{-2}. The charge on the sphere is

(a) 7.3×10^{-3} C (b) 3.7×10^{-6} C
(c) 7.3×10^{-6} C (d) 3.7×10^{-3} C

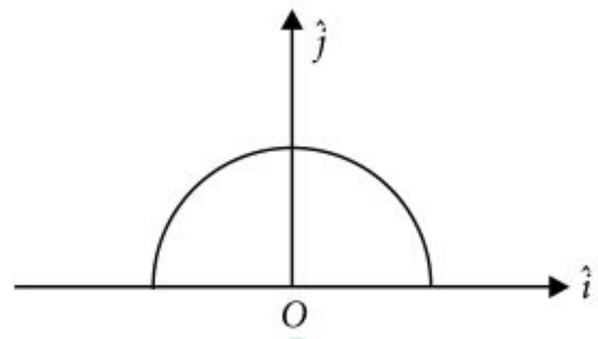
36. The nucleus of helium atom contains two protons that are separated by distance 3.0×10^{-15} m. The magnitude of the electrostatic force that each proton exerts on the other is

(a) 20.6 N (b) 25.6 N (c) 15.6 N (d) 12.6 N

37. A dipole of electric dipole moment p is placed in a uniform electric field of strength E. If θ is the angle between positive directions of p and E, then the potential energy of the electric dipole is largest when θ is

(a) $\frac{\pi}{4}$ (b) $\frac{\pi}{2}$ (c) π (d) zero

38. A thin semi-circular ring of radius r has a positive charge q distributed uniformly over it. The net electric field $\vec{E}$ at the centre O is

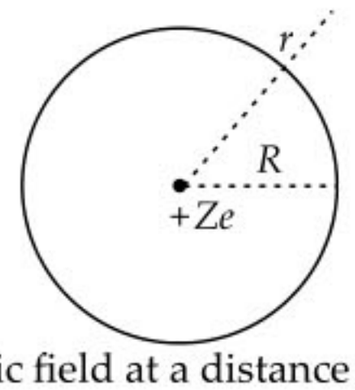


(a) $\frac{q}{2\pi^2\varepsilon_0 r^2}\hat{j}$ (b) $\frac{q}{4\pi^2\varepsilon_0 r^2}\hat{j}$
(c) $-\frac{q}{4\pi^2\varepsilon_0 r^2}\hat{j}$ (d) $-\frac{q}{2\pi^2\varepsilon_0 r^2}\hat{j}$

39. A coin is made up of Al and weighs 0.75 g. It has a square shape and its diagonal measures 17 mm. It is electrically neutral and contains equal amounts of positive and negative charges. The magnitude of these charges is (atomic mass of Al = 26.98 g)

(a) 3.47×10^4 C (b) 3.47×10^2 C
(c) 1.67×10^{20} C (d) 1.67×10^{22} C

40. An early model for an atom considered it to have a positively charged point nucleus of charge Ze, surrounded by a uniform density of negative charge upto a radius R. The atom as a whole is neutral. The electric field at a distance r from the nucleus is ($r > R$)

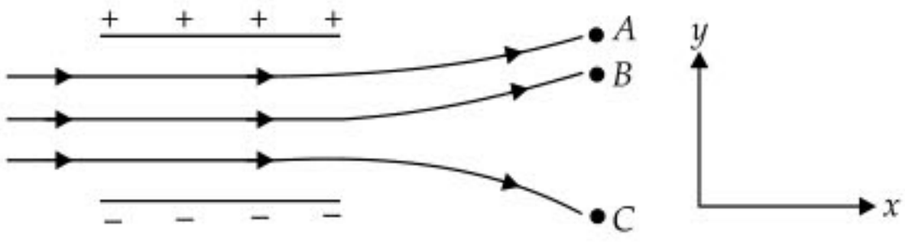


(a) $\frac{Ze}{4\pi\varepsilon_0}\left[\frac{1}{r^2} - \frac{r}{R^3}\right]$ (b) $\frac{Ze}{4\pi\varepsilon_0}\left[\frac{1}{r^3} - \frac{r}{R^2}\right]$
(c) $\frac{Ze}{4\pi\varepsilon_0}\left[\frac{r}{R^3} - \frac{1}{r^2}\right]$ (d) $\frac{Ze}{4\pi\varepsilon_0}\left[\frac{r}{R^3} + \frac{1}{r^2}\right]$

41. In a certain region of space, electric field is along the z-direction throughout. The magnitude of electric field is however not constant, but increases uniformly along the positive z-direction at the rate of 10^5 N C^{-1} m^{-1}. The force experienced by the system having a total dipole moment equal to 10^{-7} C m in the negative z– direction is

(a) -10^{-2} N (b) 10^{-2} N (c) 10^{-4} N (d) -10^{-4} N

42. The tracks of three charged particles in a uniform electrostatic field is shown in the figure. Which particle has the highest charge to mass ratio?



(a) A (b) B (c) C (d) A and B

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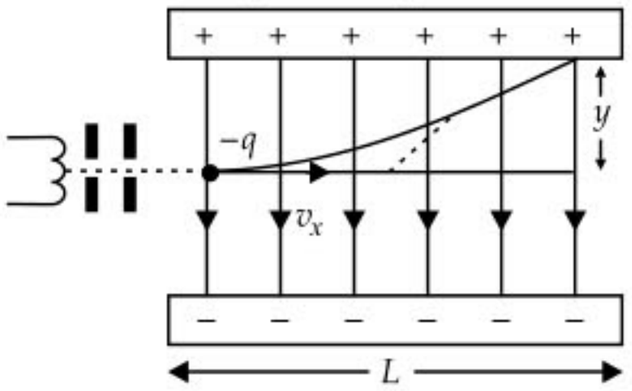
43. A particle of mass m and charge $-q$ enters the region between the two charged plates initially moving along x-axis with speed v_x as shown in figure. The length of plate is L and a uniform electric field E is maintained between the plates. The vertical deflection of the particle at the far edge of the plate is



(a) $\frac{qEL^2}{2mv_x^2}$ (b) $\frac{qEL^2}{2mv_x}$ (c) $\frac{2mv_x^2}{qEL^2}$ (d) $\frac{2mv_x}{qE^2L}$

44. Three charges of equal magnitude q is placed at the vertices of an equilateral triangle of side l. The force on a charge Q placed at the centroid of the triangle is

(a) $\frac{3Qq}{4\pi\varepsilon_0 l^2}$ (b) $\frac{Qq}{4\pi\varepsilon_0 l^2}$ (c) $\frac{Qq}{2\pi\varepsilon_0 l^2}$ (d) zero

45. A cup contains 250 g of water. Find the number of positive charges present in the cup of water.

(a) 1.34×10^{19} C (b) 1.34×10^{7} C
(c) 2.43×10^{19} C (d) 2.43×10^{7} C

DAY 15 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____

(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (b) : The electric field due to an infinite plane sheet of charge is independent of distance of point from the sheet. Applying the principle of superposition of electric field, the total electric field at P due to various plane sheets of charge will be

$$\vec{E}_P = \frac{\sigma}{2\varepsilon_0}(-\hat{k}) + \frac{2\sigma}{2\varepsilon_0}(-\hat{k}) + \frac{\sigma}{2\varepsilon_0}(-\hat{k}) = -\frac{2\sigma}{\varepsilon_0}\hat{k}$$

2. (c) : $\tau_{max} = pE\sin 90°$
$= q(2a)E = 10^{-6} \times 2 \times 10^{-2} \times 10^5$
$= 2 \times 10^{-3}$ N m

3. (c) : The electric field at a point on the axis of a uniformly charged ring

$$E = \frac{1}{4\pi\varepsilon_0}\frac{Qx}{(x^2+R^2)^{3/2}}$$

where R is the radius of the ring and x is the distance of the point on the axis from the centre of the ring.

$$\text{At } x = R,\ E = \frac{1}{4\pi\varepsilon_0}\frac{QR}{(R^2+R^2)^{3/2}} = \frac{1}{4\pi\varepsilon_0}\frac{QR}{(2R^2)^{3/2}}$$

$$\text{At } x = \frac{R}{\sqrt{2}},\ E' = \frac{1}{4\pi\varepsilon_0}\frac{Q\left(\frac{R}{\sqrt{2}}\right)}{\left(\left(\frac{R}{\sqrt{2}}\right)^2 + R^2\right)^{3/2}} = \frac{1}{4\pi\varepsilon_0}\frac{2QR}{(3R^2)^{3/2}}$$

$$\therefore \quad \frac{E}{E'} = \frac{(3)^{3/2}}{2(2)^{3/2}} = \frac{3\sqrt{3}}{4\sqrt{2}}$$

4. (a) : The magnitude of electric field intensity due to a thin infinitely long straight wire of uniform linear charge density λ is

$$E = \frac{1}{4\pi\varepsilon_0}\frac{2\lambda}{r}$$

where r is the perpendicular distance of the point from the wire.

Here, $\lambda = \frac{1}{3}$ C m^{-1}, $r = 18$ cm $= 18 \times 10^{-2}$ m

$$\therefore \quad E = \frac{9\times10^9 \times 2 \times \frac{1}{3}}{18\times10^{-2}} = \frac{9\times10^9\times2}{3\times18\times10^{-2}}\ \text{N C}^{-1}$$

$$= \frac{1}{3}\times10^{11}\ \text{N C}^{-1} = 0.33\times10^{11}\ \text{N C}^{-1}$$

5. (b) : Let $q_1 = q$ μC and $q_2 = (8 - q)$ μC
$r = 3$ m, $F = 0.012$ N
According to Coulomb's law

$$F = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}$$

$$0.012 = \frac{9\times10^9 q(8-q)\times10^{-12}}{3^2}$$

$$0.012 = q(8-q)10^{-3}$$

or $\quad q^2 - 8q + 12 = 0$

Solving the quadratic equation, we get
$q = 6$ or 2
Hence, the two charges are 6 μC and 2 μC.

6. (c) : According to Gauss's law

$$\phi_E = \frac{Q_{enclosed}}{\varepsilon_0}$$

If the radius of the Gaussian surface is doubled, the outward electric flux will remain the same. This is because electric flux depends only on the charge enclosed by the surface.

7. (c) : The direction of electric field intensity $\left(\vec{E}\right)$ at a point on the equatorial line of electric dipole of dipole moment $(\vec{p})$ is perpendicular to equatorial line and opposite to $(\vec{p})$.

8. (b) : According to Gauss's law

Electric flux, $\phi = \frac{q}{\varepsilon_0}$

where, q = total charge enclosed by closed surface

$$\therefore \quad \phi = \frac{1.25+7+1-0.4}{\varepsilon_0}$$

$$= \frac{8.85\ \text{C}}{8.85\times10^{-12}\ \text{C}^2\ \text{N}^{-1}\ \text{m}^{-2}} = 10^{12}\ \text{N m}^2\ \text{C}^{-1}$$

9. (b) : Positive charge tends to move normally away from the conductor *i.e* starts or ends only at 90° to the surface of the conductor. Thus, the lines of force are parallel and normal to the surface of conductor. So curve (b) cannot represent electrostatic field lines.

10. (a) : Here, $\vec{E} = 24\hat{i} + 30\hat{j} + 28\hat{k}$ N C^{-1}

$\vec{S} = 20\hat{i}$ m^2

Electric flux, $\phi = \vec{E}\cdot\vec{S}$
$= (24\hat{i} + 30\hat{j} + 28\hat{k}\ \text{N C}^{-1})\cdot(20\hat{i}\ \text{m}^2)$
$= 480$ N m^2 C^{-1}

11. (d) : For the system to be in equilibrium, net force on $q = 0$.

$$\frac{Qq}{4\pi\varepsilon_0 x^2} + \frac{qq}{4\pi\varepsilon_0(2x)^2} = 0$$

$$Q = -\frac{q}{4} \text{ or } \frac{Q}{q} = -\frac{1}{4}$$

12. (d) : Here, $\vec{E} = 2\hat{i} + 3\hat{j} + \hat{k}$ NC^{-1}

$\vec{S} = 10\hat{i}$ m^2

Electric flux, $\phi_E = \vec{E}\cdot\vec{S}$
$= (2\hat{i} + 3\hat{j} + \hat{k}\ \text{NC}^{-1})\cdot(10\hat{i}\ \text{m}^2)$
$= 20$ Nm^{2}C^{-1}

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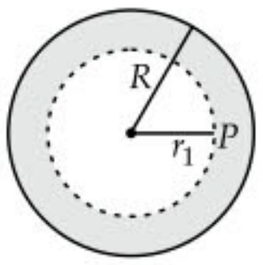
13. (c) : In figure dotted sphere of radius r_1 is the Gaussian surface.

According to Gauss's theorem

$$\oint \vec{E}\cdot d\vec{s} = \frac{q_{\text{inside}}}{\varepsilon_0}$$

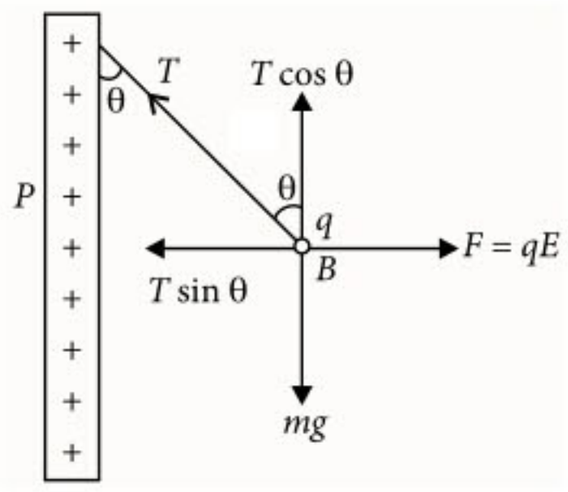


$$Eds\cos 0° = \frac{1}{\varepsilon_0}\rho(r)\times dV$$

$$E(4\pi r_1^2)\times 1 = \frac{Qr_1}{\varepsilon_0 \pi R^4}\times\left(\frac{4}{3}\pi r_1^3\right)$$

$$E = \frac{Q\cdot 4\pi r_1^4}{3\varepsilon_0\cdot \pi R^4(4\pi r_1^2)} = \frac{Qr_1^2}{3\pi\varepsilon_0 R^4}$$

14. (d) :



According to diagram,

$T\sin\theta = qE = q(\sigma/\varepsilon_0) = q\sigma/\varepsilon_0$

and $T\cos\theta = mg$

Hence, $\tan\theta = \dfrac{q\sigma}{\varepsilon_0 mg}$

or $\sigma = \left(\dfrac{\varepsilon_0 mg}{q}\right)\tan\theta$ or $\sigma \propto \tan\theta$

15. (c) : According to Gauss's theorem,

Electric flux through the sphere $= \dfrac{q}{\varepsilon_0}$

∴ Electric flux through the hemisphere

$$= \frac{1}{2}\frac{q}{\varepsilon_0}$$

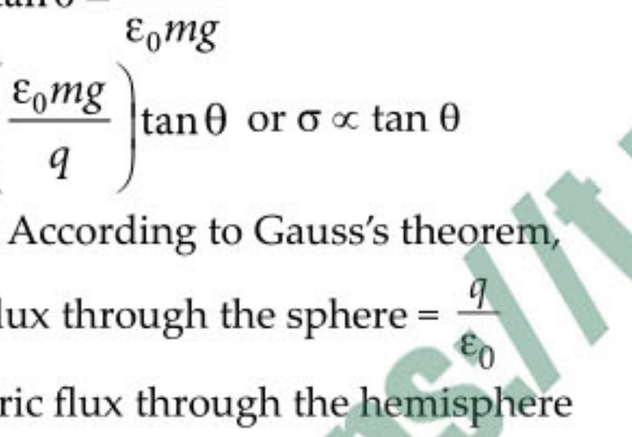
$$= \frac{10\times 10^{-6}}{2\times 8.854\times 10^{-12}}$$

$$= 0.56\times 10^6\ \text{Nm}^2\,\text{C}^{-1}$$

$$\approx 0.6\times 10^6\ \text{Nm}^2\,\text{C}^{-1}$$

$$= 6\times 10^5\ \text{Nm}^2\,\text{C}^{-1}$$

16. (b) :



The electric field at C due to charge $+10^{-7}$ C at A is

$$\vec{E}_1 = \frac{1}{4\pi\varepsilon_0}\frac{10^{-7}}{(0.2)^2}\ \text{along } AC$$

The electric field at C due to charge -10^{-7} C at B is

$$\vec{E}_2 = \frac{1}{4\pi\varepsilon_0}\frac{10^{-7}}{(0.2)^2}\ \text{along } CB$$

As $|\vec{E}_1| = |\vec{E}_2|$

By symmetry the vertical components will cancel out and horizontal components will add.

∴ The resultant electric field at C is

$E = 2E_1\cos 60°$

$$= 2\times\frac{1}{4\pi\varepsilon_0}\frac{10^{-7}}{(0.2)^2}\times\frac{1}{2}$$

$$= \frac{9\times 10^9\times 10^{-7}}{(0.2)^2} = 2.2\times 10^4\ \text{N/C}$$

17. (c) : The electric field due to an infinitely long straight uniformly charged wire at a distance r is

$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

where λ is the uniform linear charge density and ε_0 is the permittivity of free space.

∴ $E \propto \dfrac{1}{r}$

18. (b) : According to Gauss's law

Electric flux linked with a cube enclosing a charge q is

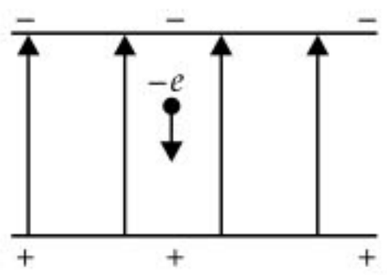
$$\phi = \frac{1}{\varepsilon_0}q$$

As cube is a symmetrical body with 6-faces and the point charge is at its centre, so electric flux linked with each face is

$$\phi_F = \frac{1}{6}\phi = \frac{q}{6\varepsilon_0}$$

19. (d) : In figure the field is upward.

So the negatively charged electron experiences a downward force.



∴ The acceleration of electron is $a_e = \dfrac{eE}{m_e}$ ...(i)

The time required by the electron to fall through a distance h is

$$t_e = \sqrt{\left(\frac{2h}{a_e}\right)} = \sqrt{\frac{2hm_e}{eE}} \quad \text{(using (i))}$$

$$= \left[\frac{2\times 1.5\times 10^{-2}\times 9.11\times 10^{-31}}{1.6\times 10^{-19}\times 2\times 10^4}\right]^{1/2} = 2.9\times 10^{-9}\ \text{s}$$

20. (c) : Here, radius of sphere = 10 cm

Distance of point from the centre of the sphere, $r = 20\ \text{cm} = 0.2\ \text{m}$

Electric field, $E = 1.2\times 10^3\ \text{N C}^{-1}$

As $E = \dfrac{q}{4\pi\varepsilon_0 r^2}$

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$\therefore \quad q = (4\pi\varepsilon_0 r^2)\, E$

$$= \frac{(0.2)^2 \times (-1.2\times10^3)}{9\times10^9} = -5.3\times10^{-9}\ \text{C}$$

21. (a) : Here, $n = 10$, $E = 3.65\times10^4\ \text{N C}^{-1}$

$\rho_{oil} = 1.26\ \text{g cm}^{-3} = 1.26\times10^3\ \text{kg m}^{-3}$

As the droplet is stationary,

weight of droplet = force due to electric field

or $\quad \frac{4}{3}\pi r^3 \rho g = Ene$

$$\therefore \quad r^3 = \frac{3Ene}{4\pi\rho g}$$

$$\therefore \quad r^3 = \frac{3\times3.65\times10^4\times10\times1.6\times10^{-19}}{4\times3.14\times1.26\times10^3\times9.8}$$

$$= 1.13\times10^{-18}$$

or $\quad r = (1.13\times10^{-18})^{1/3} \quad = 1.0\times10^{-6}\ \text{m}$

22. (d) : At the centre of the ring, $E = 0$. When a positive charge ($q > 0$) is displaced away from the centre in the plane of the ring, say to the right, force of repulsion on q, due to charge on right half increases and due to charge on left half decreases. Therefore, charge q is pushed back towards the centre. So option (a) is correct.

When charge q is negative ($q < 0$), force is of attraction. Therefore, charge q displaced to the right continues moving to the right till it hits the ring.

Along the axis of the ring, at a distance r from the centre,

$$E = \frac{Qr}{4\pi\varepsilon_0 (r^2 + a^2)^{3/2}}$$

If charge q is negative ($q < 0$), it will perform SHM for small displacement along the axis.

23. (c) : The acceleration of the electron due to given coulombic force F is

$$a_e = \frac{F}{m_e} \qquad \text{...(i)}$$

where m_e is the mass of the electron.

The acceleration of the proton due to same force F is

$$a_p = \frac{F}{m_p} \qquad \text{...(ii)}$$

where m_p is the mass of the proton.

Divide (ii) by (i), we get

$$\frac{a_p}{a_e} = \frac{m_e}{m_p} \quad \therefore \quad a_p = \frac{a_e m_e}{m_p} = \frac{(2.5\times10^{22}\ \text{m s}^{-2})(9.1\times10^{-31}\ \text{kg})}{(1.67\times10^{-27}\ \text{kg})}$$

$$= 13.6\times10^{18}\ \text{m s}^{-2} \approx 1.4\times10^{19}\ \text{m s}^{-2}$$

24. (c) : Here, $l = 2.4$ m, $r = 4.6$ mm $= 4.6\times10^{-3}$ m

$q = -4.2\times10^{-7}$ C

Linear charge density,

$$\lambda = \frac{q}{l} = \frac{-4.2\times10^{-7}}{2.4} = -1.75\times10^{-7}\ \text{C m}^{-1}$$

Electric field

$$E = \frac{\lambda}{2\pi\varepsilon_0 r} = \frac{-1.75\times10^{-7}}{2\times3.14\times8.854\times10^{-12}\times4.6\times10^{-3}}$$

$$= -6.8\times10^5\ \text{N C}^{-1}$$

25. (b) : Here, between an electron and a proton

Electrostatic force, $|F_e| = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$

Gravitational force, $|F_g| = \frac{Gm_e m_p}{r^2}$

$$\therefore \quad \frac{|F_e|}{|F_g|} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{Gm_e m_p}$$

$$= \frac{9\times10^9\times(1.6\times10^{-19})^2}{6.67\times10^{-11}\times9\times10^{-31}\times1.66\times10^{-27}} = 2.3\times10^{39}$$

26. (d) : $\phi = ar^2 + b$

Electric field, $E = \frac{-d\phi}{dr} = -2ar$ ...(i)

According to Gauss's theorem,

$$\oint \vec{E}\cdot d\vec{S} = \frac{q_{inside}}{\varepsilon_0}$$

or $\quad -2ar\,4\pi r^2 = \frac{q_{inside}}{\varepsilon_0}$ (Using (i))

$$q_{inside} = -8\varepsilon_0 a\pi r^3$$

Charge density inside the ball is

$$\rho_{inside} = \frac{q_{inside}}{\frac{4}{3}\pi r^3} \quad \therefore \quad \rho_{inside} = \frac{-8\varepsilon_0 a\pi r^3}{\frac{4}{3}\pi r^3}$$

$$\rho_{inside} = -6a\varepsilon_0$$

27. (c)

28. (b) : Here, number of electrons removed = number of atoms in 1 g

or $\quad n = \frac{4\times10^{20}}{10^3} = 4\times10^{17}$

$\therefore$ charge, $q = ne = 4\times10^{17}\times1.6\times10^{-19}\ \text{C}$

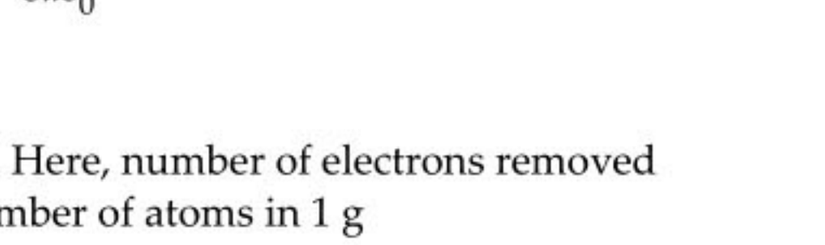
$$= 6.4\times10^{-2}\ \text{C}$$

29. (d) : The point lies on equatorial line of a short dipole.

$$\therefore \quad E = \frac{ql}{4\pi\varepsilon_0 r^3} = \frac{9\times10^9\times10^{-6}\times10^{-8}}{(10^{-1})^3}$$

$$= 9\times10^{-2}\ \text{N C}^{-1}$$

30. (c) :



Here, $q = \pm 20\ \mu\text{C} = \pm 20\times10^{-6}$ C

$2a = 10$ mm $= 10\times10^{-3}$ m

$r = OP = 10$ cm $= 10\times10^{-2}$ m

$|\vec{p}| = q\times2a = 20\times10^{-6}\times10\times10^{-3} = 2\times10^{-7}$ Cm

The electric field along BP, $E = \frac{2\vec{p}\,r}{4\pi\varepsilon_0 (r^2 - a^2)^2}$

As $a \ll r$,

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$$E = \frac{2|\vec{p}|}{4\pi\varepsilon_0 r^3} = \frac{2\times2\times10^{-7}\times9\times10^{9}}{(10\times10^{-2})^3}$$

$$= 3.6 \times 10^6 \text{ N C}^{-1}$$

31. (c) : At the distance of closest approach (r)

K.E. = P.E.

$$\therefore \frac{1}{2}mv^2 + \frac{1}{2}mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$$

$$mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$$

$$r = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{mv^2} = \frac{9\times10^9\times(1.6\times10^{-19})^2}{9\times10^{-31}\times(10^6)^2}$$

$$= 2.56 \times 10^{-10} \text{ m}$$

32. (a) : Here, $E = 2 \times 10^3$ N C^{-1} along + x-axis

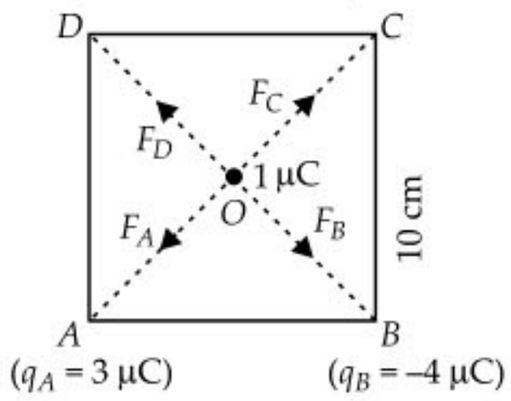
Surface area, $S = (10 \text{ cm})^2 = 10^2 \times 10^{-4}$ m^2 = 10^{-2} m^2.

When plane is parallel to yz plane, $\theta = 0°$

So $\phi = E\,S\cos\theta = 2 \times 10^3 \times 10^{-2}\cos0°$

$= 20$ N C^{-1} m^2

33. (d) :



From figure, length of diagonal of the square

$= AC = BD = \sqrt{10^2 + 10^2} = 10\sqrt{2}$ cm

$$OA = OB = OC = OD = \frac{10\sqrt{2}}{2} = \frac{10}{\sqrt{2}} \text{ cm}$$

Forces of repulsion on 1 μC charge at O due to 3 μC charges, at A and C are equal and opposite. So they cancel each other.

Similarly, forces of attraction on 1 μC charge at O due to –4 μC charges at B and D are also equal and opposite. So they also cancel each other.

Hence the net force on the charge of 1 μC at O is zero.

34. (d) : According to Gauss's theorem in electrostatics

$$\oint \vec{E}\cdot\vec{ds} = \frac{q}{\varepsilon_0}$$

Here q is charge enclosed by the surface.

If the charge is outside the surface, then $q_{\text{inside}} = 0$

Also, $\oint \vec{E}\cdot d\vec{s} = 0$.

So, both (b) and (c) are correct.

35. (d) : Here, $D = 2r = 4.4$ m, or $r = 2.2$ m

$\sigma = 60$ μC m^{-2}

Charge on the sphere, $q = \sigma \times 4\pi r^2$

$$= 60\times10^{-6}\times4\times\frac{22}{7}\times(2.2)^2 = 3.7 \times 10^{-3} \text{ C}$$

36. (b) : Charge of proton, $q_p = 1.6 \times 10^{-19}$ C

Distance between the protons,

$r = 3 \times 10^{-15}$ m

The magnitude of electrostatic force between protons is

$$F_e = \frac{q_p\, q_p}{4\pi\varepsilon_0 r^2} = \frac{9\times10^9\times1.6\times10^{-19}\times1.6\times10^{-19}}{(3\times10^{-15})^2}$$

$$= 25.6 \text{ N}$$

37. (c) : The potential energy of an electric dipole in a uniform electric field is

$U = -\vec{p}\cdot\vec{E}$

$U = -pE\cos\theta$

For U to be maximum

$\cos\theta = -1 \Rightarrow \theta = \pi$

38. (d) : $E = \int_0^{\pi} dE\sin\theta$

$$\Rightarrow E = \int_0^{\pi} k\frac{dq}{r^2}\sin\theta$$

$$= \frac{k}{r^2}\int_0^{\pi}\left(\frac{qd\theta}{\pi}\right)\sin\theta \quad \left(\text{as } dq = \frac{qd\theta}{\pi}\right)$$

$$= \frac{kq}{\pi r^2}\int_0^{\pi}\sin\theta\, d\theta = \frac{q}{2\pi^2\varepsilon_0 r^2} \quad \left(\text{as } \int_0^{\pi}\sin\theta\, d\theta = 2\right)$$

or $\vec{E} = -\frac{q}{2\pi^2\varepsilon_0 r^2}\hat{j}$ (as $\vec{E}$ is directed along $-Y$-axis)

39. (a) : Mass of the coin = 0.75 g, $Z_{Al} = 13$

Atomic mass of aluminium = 26.98 g

Avogadro's number = 6.02×10^{23}

Number of Al atoms in the coin,

$$N = \frac{6.02\times10^{23}}{26.98}\times0.75 = 1.67 \times 10^{22}$$

As charge number of Al is 13, each atom of Al contain 13 protons and 13 electrons.

Magnitude of positive and negative charges in one coin

$= NZ_{Al}\,e$

$= 1.67 \times 10^{22} \times 13 \times 1.6 \times 10^{-19}$ C

$= 3.47 \times 10^4$ C

40. (a) : Charge on nucleus = + Ze

Total negative charge = – Ze

($\because$ atom is electrical neutral]

Negative charge density, $\rho = \frac{\text{charge}}{\text{volume}} = \frac{-Ze}{\frac{4}{3}\pi R^3}$

i.e. $\rho = -\frac{3}{4}\frac{Ze}{\pi R^3}$ ...(i)

Consider a Gaussian surface with radius r.

By Gauss's theorem

$\phi = E(r) \times 4\pi r^2 = \frac{q}{\varepsilon_0}$ ...(ii)

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Charge enclosed by Gaussian surface

$$q = Ze + \frac{4\pi r^3}{3}\rho = Ze - Ze\frac{r^3}{R^3}$$ (Using (i))

From (ii)

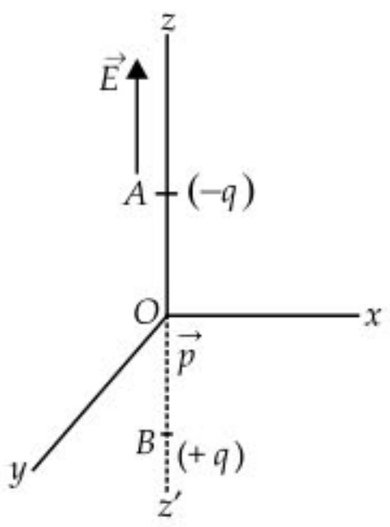
$$E(r) = \frac{q}{4\pi\varepsilon_0 r^2} = \frac{Ze - Ze\dfrac{r^3}{R^3}}{4\pi\varepsilon_0 r^2} = \frac{Ze}{4\pi\varepsilon_0}\left[\frac{1}{r^2} - \frac{r}{R^3}\right]$$

41. (a) : Consider an electric dipole with $-q$ charge at A and $+q$ charge at B, placed along z-axis, such that its dipole moment is in negative z direction.

i.e., $p_z = -10^{-7}$ Cm

The electric field is along positive direction of z-axis, such that

$$\frac{dE}{dz} = 10^5 \text{ N C}^{-1} \text{ m}^{-1}$$



From $F = qdE = (q \times dz) \times \dfrac{dE}{dz}$

$$= p\frac{dE}{dz}$$

Force experienced by the system in the negative z-direction

$$F = -p \times \left(-\frac{dE}{dz}\right)$$

$$= 10^{-7} \times (-10^5) = -10^{-2} \text{ N}$$

42. (c) : Particles A and B have negative charges because they are being deflected towards the positive plate of the electrostatic field. Particle C has positive charge because it is being deflected towards the negative plate.

Deflection of charged particle in time t in y-direction

$$h = 0 \times t + \frac{1}{2}at^2 = \frac{1}{2}\frac{qE}{m}t^2$$

i.e. $h \propto q/m$

As the particle C suffers maximum deflection in y-direction, so it has highest charge to mass q/m ratio.

43. (a) : Here, in the vertical direction,

initial velocity, $v = 0$

acceleration, $a = \dfrac{F}{m} = \dfrac{qE}{m}$ ...(i) ($\because$ $F = qE$)

Time taken to cross the field,

$$t = \frac{\text{distance}}{\text{velocity}} = \frac{L}{v_x}$$ ...(ii)

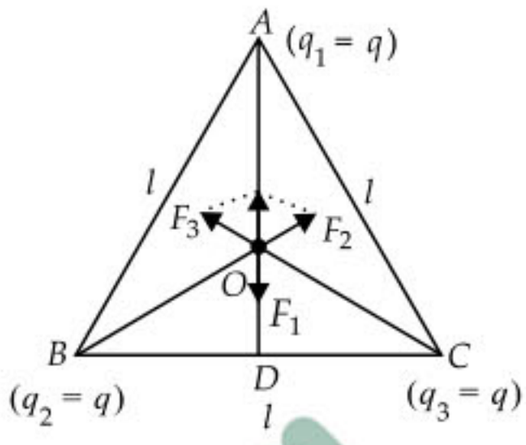
($\because$ velocity along the horizontal direction is constant)

Now, $s = vt + \dfrac{1}{2}at^2$

$\therefore$ deflection, $y = 0 + \dfrac{1}{2}\left(\dfrac{qE}{m}\right)\left(\dfrac{L}{v_x}\right)^2$ [Using (i) and (ii)]

$$\therefore \quad y = \frac{qEL^2}{2mv_x^2}$$

44. (d) : From figure,



$$AD = AB\cos 30° = \frac{l\sqrt{3}}{2}$$

Distance AO of the centroid O from A

$$= \frac{2}{3}AD = \frac{2l}{3}\frac{\sqrt{3}}{2} = \frac{l}{\sqrt{3}}$$

$\therefore$ Force on Q at O due to charge $q_1 = q$ at A

$$F_1 = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{(l/\sqrt{3})^2} = \frac{3Qq}{4\pi\varepsilon_0 l^2}$$, along AO

Similarly, force on Q due to charge $q_2 = q$ at B

$$F_2 = \frac{3Qq}{4\pi\varepsilon_0 l^2}$$ along BO

and force on Q due to charge $q_3 = q$ at C

$$F_3 = \frac{3Qq}{4\pi\varepsilon_0 l^2}$$, along CO

Angle between forces F_2 and $F_3 = 120°$

By parallelogram law, resultant of F_2 and $F_3 = \dfrac{3Qq}{4\pi\varepsilon_0 l^2}$ along OA

$\therefore$ Total force on $Q = \dfrac{3Qq}{4\pi\varepsilon_0 l^2} - \dfrac{3Qq}{4\pi\varepsilon_0 l^2} = 0$

45. (b) : Mass of water = 250 g

Molecular mass of water = 18 g

Number of molecules in 18 g of water

(Avogadro's Number) = 6.02×10^{23}

$\therefore$ Number of molecules in one cup of water

$$= \frac{250}{18} \times 6.02 \times 10^{23}$$

Each molecule of water contains two hydrogen atoms and one oxygen atom, *i.e.* 10 electrons and 10 protons.

$\therefore$ Total positive and negative charge has the same magnitude and is

$$= \frac{250}{18} \times 6.02 \times 10^{23} \times 10 \times 1.6 \times 10^{-19} \text{ C}$$

$$= 1.34 \times 10^7 \text{ C}$$

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Electrostatic Potential and Capacitance

Electric Potential

The electric potential at a point in a field is defined as the work done in moving unit positive charge from infinity to the point.

$$i.e., \quad V = \frac{W}{q}$$

Electric potential due to a positive charge is taken to be positive and that due to a negative charge is taken to be negative.

Electric potential is a scalar quantity. The SI unit of potential is volt and its dimensional formula is $[ML^2T^{-3}A^{-1}]$.

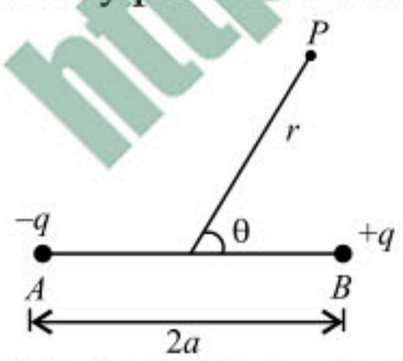
Electric potential at a point distant r from a point charge q is

$$V = \frac{q}{4\pi\varepsilon_0 r}$$

Electric potential due to group of charges : The electric potential at a point due to a group of charges is equal to the algebraic sum of the electric potentials due to individual charges at that point.

$$V = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} + ... + \frac{q_n}{r_n}\right) = \frac{1}{4\pi\varepsilon_0} \sum_{i=1}^{n} \frac{q_i}{r_i}$$

Electric potential at any point due to an electric dipole



The electric potential at point P due to an electric dipole

$$V = \frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r^2}$$

Special cases :

- When the point P lies on the axial line of dipole *i.e.*, $\theta = 0°$.

$$V = \frac{p}{4\pi\varepsilon_0 r^2}$$

- When the point P lies on the equatorial line of the dipole, *i.e.*, $\theta = 90° \quad \therefore \quad V = 0$.

Electric potential due to a uniformly charged spherical shell of uniform surface charge density s and radius R at a distance r from the centre of the shell is given as follows :

- At a point outside the shell *i.e.*, $r > R$

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

- At a point on the shell *i.e.*, $r = R$

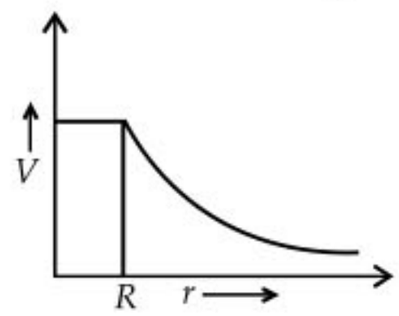
$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{R}$$

- At a point inside the shell *i.e.*, $r < R$

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{R}$$

Here, $q = 4\pi R^2\sigma$

The variation of V with r for a uniformly charged thin spherical shell is shown in the figure.



Electric potential due to a non-conducting solid sphere of uniform volume charge density ρ and radius R distant r from the sphere is given as follows :

- At a point outside the sphere *i.e.*, $r > R$

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

- At a point on the sphere *i.e.*, $r = R$

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{R}$$

- At a point inside the sphere *i.e.*, $r < R$

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q(3R^2 - r^2)}{2R^3}$$

Here, $q = \frac{4}{3}\pi R^3\rho$

Equipotential Surfaces

All points in a field which have the same potential can be imagined as lying on a surface is called an equipotential surface.

When a charge moves on such a surface no energy change occurs and no work is done.

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The force due to the field must therefore act at right angles to the equipotential surface at any point and so equipotential surfaces and field lines always intersect at right angles.

Properties of equipotential surfaces

- Electric lines of force always intersect equipotential surfaces normally and are directed from higher potential to lower potential, as the direction of electric field is along the direction of decreasing potential.
- Equipotential surfaces never intersect each other.
- No net work is done on a charge by an electric field when the charge moves between two points on the same equipotential surface.

Relationship between $\vec{E}$ and $\vec{V}$

$$\vec{E} = -\vec{\nabla}V$$

where $\vec{\nabla} = \left(\hat{i}\frac{\partial}{\partial x} + \hat{j}\frac{\partial}{\partial y} + \hat{k}\frac{\partial}{\partial z} \right]$

–ve sign shows that the direction of $\vec{E}$ is the direction of decreasing potential.

Electric potential energy of a system of two point charges

$$U = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}}$$

where r_{12} is the distance between q_1 and q_2.

Electric potential energy of a system of n point charges

$$U = \frac{1}{4\pi\varepsilon_0}\sum_{\substack{\text{all pairs}\\ \text{of charges}}}\frac{q_j q_k}{r_{jk}}$$

The SI unit of electric potential energy is joule.

Potential Energy of a dipole in an external Electric field.

Since net force on electric dipole in uniform electric field is zero, so no work is done in moving the electric dipole in uniform electric field is zero, however some work is done in rotating the dipole against the torque acting on it. So, small work done in rotating the dipole by an angle dq in uniform electric field $\vec{E}$ is

$$dW = \tau \times d\theta = pE\sin\theta \times d\theta$$

Hence, net work done in rotating the dipole from angle θ_i to θ_f in uniform electric field is

$$W = \int_{\theta_i}^{\theta_f} pE\sin\theta \cdot d\theta = pE\left[-\cos\theta\right]_{\theta_i}^{\theta_f}$$

or $W = pE\,[-\cos\theta_f + \cos\theta_i] = pE\,[\cos q_i - \cos q_f]$

If initially, the dipole is placed at an angle $\theta_i = 90°$ to the direction of electric field, and is then rotated to the angle $\theta_f = \theta$, then net work done is

$$W = pE\,[\cos 90° - \cos\theta]$$

or $W = -pE\cos\theta$

This gives the work done in rotating the dipole through an angle θ in uniform electric field, which gets stored in it in the form of potential energy *i.e.*,

$$U = -pE\cos\theta$$

This gives potential energy stored in electric dipole of moment $\vec{p}$ when placed in uniform electric field $\vec{E}$ at an angle θ with its direction.

(i) when $\theta = 0°$, then

$U_{min} = -pE$

So, potential energy of an electric dipole is minimum, when it is placed with its dipole moment parallel to the direction of electric field $\vec{E}$ and so it is called its most stable equilibrium position.

(ii) when $\theta = 90°$, then

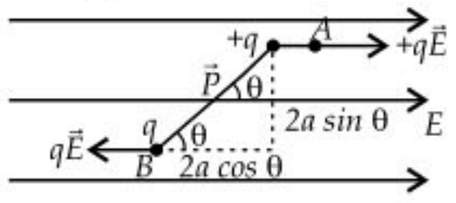
$U = 0$

So, potential energy of an electric dipole is zero, when it is placed perpendicular to the direction of electric field $\vec{E}$ and so it is called its zero energy position.

(iii) when $\theta = 180°$, then

$U_{max} = +pE$

So, potential energy of an electric dipole is maximum, when it is placed with its dipole moment $\vec{p}$ anti parallel to the direction of electric field $\vec{E}$ and so it is called its most unstable equilibrium position.



Conductors and Insulators

Those substances which can easily allow electricity to pass through them are known as conductors. They have a large number of free charge carriers that are free to move inside the material. *e.g.*, metals, human beings, earth etc.

In insulators, the charges remain fixed at their places *i.e.*, insulators do not have free charges to move.

Electric properties of conductors

Basic electrostatics properties of a conductor are as follows :

- Inside a conductor, electric field is zero.
- At the surface of a charged conductor, electric field must be normal to the surface at every point.
- The interior of a conductor can have no excess charge in the static situation.
- Electric potential is constant throughout the volume of the conductor and has the same value (as inside) on its surface.
- Electric field at the surface of a charged conductor, $\vec{E} = \frac{\sigma}{\varepsilon_0}\hat{n}$

  where σ is the surface charge density and $\hat{n}$ is a unit vector normal to the surface in the outward direction.

Electrostatic shielding : It is the phenomenon of protecting a certain region of space from external electric field.

Polar & non polar molecules

Polar molecule : A polar molecule is one in which the centres of positive and negative charges are separated (even when there is no external field). A polar molecule has a permanent dipole moment *e.g.*, water (H_2O) and HCl.

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Non-polar molecule : A non-polar molecule is one in which the centres of positive and negative charges coincide. A non-polar molecule has no permanent dipole moment. *e.g.,* oxygen (O_2) and hydrogen (H_2).

Capacitor & Capacitance

Capacitor

A capacitor is designed to store electric charge and basically consists of two conductors, such as a pair of parallel metal plates, separated by an insulator. The symbol for a capacitor is ⊣|⊢ and the conductors are usually referred to as 'plates' whatever their form.

Capacitance

Ability to store charge by a conductor is called capacity of the conductor.

Capacitance (C) of a capacitor is the ratio of charge(Q) given and the potential (V) to which it is raised.

$$C = \frac{Q}{V}$$

The SI unit of capacitance is **farad** (F).

1 millifarad (mF) = 10^{-3} farad

1 microfarad (μF) = 10^{-6} farad

1 picofarad (pF) = 10^{-12} farad.

Capacitance is a scalar quantity.

The dimensional formula of capacitance is $[M^{-1}L^{-2}T^4A^2]$.

Capacitance of spherical conductor

Capacitance of a spherical conductor of radius R is

$$C = 4\pi\varepsilon_0 R$$

Taking earth to be a conducting sphere of radius 6400 km, its capacitance will be

$$C = 4\pi\varepsilon_0 R = \frac{6.4\times10^6}{9\times10^9} = 711\ \mu F$$

Type of capacitors

Depending on their geometry, capacitors are classified as:

- Parallel plate capacitor
- Cylindrical capacitor
- Spherical capacitor

Parallel plate capacitor : It consists of two similar flat conducting plates, arranged parallel to one another, separated by a distance. Its capacitance is given by

$C = \frac{\varepsilon_0 A}{d}$ (when air is between the plates)

$C = \frac{K\varepsilon_0 A}{d}$ (when dielectric is between the plates)

where A is area of each plate and d is separation between the two plates.

When a dielectric slab of thickness t and dielectric constant K is introduced between the plates, then the capacitance of a parallel plate capacitor is given by

$$C = \frac{\epsilon_0 A}{\left(d - t + \frac{t}{K}\right)}$$

When a metallic conductor of thickness t is introduced between the plates, then capacitance of a parallel plate capacitor is given by

$$C = \frac{\varepsilon_0 A}{d - t}$$

Cylindrical capacitor : It consists of two co-axial cylinders of same length.

Capacitance of an air filled cylindrical capacitor is

$$C = \frac{2\pi\varepsilon_0 L}{\ln\left(\frac{b}{a}\right)}$$

where a and b are the respective inner and outer radii and L is the length.

Spherical capacitor : It consists of two concentric spherical shells.

Capacitance of an air filled spherical capacitor is

$$C = 4\pi\varepsilon_0 \frac{ab}{b-a}$$

where a and b are the inner and outer radii respectively.

Grouping of capacitors

Capacitors in series : For n capacitors connected in series, the equivalent capacitance C_S is given by

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + ... + \frac{1}{C_n}$$

Capacitors in parallel : For n capacitors connected in parallel, the equivalent capacitance C_P is given by

$$C_P = C_1 + C_2 + ... + C_n$$

When capacitors are connected in series, the charge through each capacitor is same.

When capacitors are connected in parallel, the potential difference across each capacitor is same.

Energy stored in a capacitor

Work done in charging a capacitor gets stored in the capacitor in the form of its electric potential energy and it is given by

$$U = \frac{1}{2}CV^2 = \frac{1}{2}QV = \frac{1}{2}\frac{Q^2}{C}$$

Energy Density

The energy stored per unit volume in the electric field between the plates is called energy density (u). It is given by

$$u = \frac{1}{2}\varepsilon_0 E^2$$

Sharing of Charges

When two capacitors charged to different potentials are connected by a conducting wire, charge flows from the one at higher potential to the other at lower potential till their potentials become equal. The equal potential is called common potential. It is given by

$$V = \frac{\text{Total charge}}{\text{Total capacity}} = \frac{Q_1 + Q_2}{C_1 + C_2} = \frac{C_1V_1 + C_2V_2}{C_1 + C_2}$$

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In sharing charges, there is absolutely no loss of charge. Some energy is, however, lost in the process in the form of heat etc. which is given by

$$U_1 - U_2 = \frac{C_1 C_2 (V_1 - V_2)^2}{2(C_1 + C_2)}.$$

Effect of Dielectric

When a dielectric slab of dielectric constant K is introduced between the plates of a charged parallel plate capacitor and the charging battery is disconnected, then

- potential difference between the plates decreases *i.e.*, $V = \frac{V_0}{K}$
- capacitance C increases *i.e.*, $C = KC_0$
- charge on a capacitor remains same *i.e.*, $Q = Q_0$
- electric field between the plates decrease *i.e.*, $E = E_0/K$
- energy stored in a capacitor decreases *i.e.*, $U = \frac{U_0}{K}$

When a dielectric slab of dielectric constant K is introduced between the plates of a charged parallel plate capacitor and the charging battery remains connected, then

- charge on capacitor increases *i.e.*, $Q = KQ_0$
- capacitance increases *i.e.*, $C = KC_0$
- potential difference between the plates remains same *i.e.*, $V = V_0$
- electric field between the plates remains unchanged *i.e.*, $E = E_0$
- energy stored in the capacitor increases *i.e.*, $U = KU_0$ where Q_0, C_0, V_0, E_0 and U_0 represents the charge, capacitance, potential difference, electric field and energy stored in the capacitor of a charged air filled parallel plate capacitor.

Van de Graaff Generator

A Van de Graaff generator consists of a large spherical conducting shell (a few metres in diameter). By means of a moving belt and suitable brushes, charge is continuously transferred to the shell, and potential difference of the order of several million volts is built up, which can be used for accelerating charged particles.

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EXAM DRILL

1. The plates of a parallel plate capacitor are charged up to 100 V. A 2 mm thick plate is inserted between the plates, then to maintain the same potential difference, the distance between the capacitor plates is increased by 1.6 mm. The dielectric constant of the plate is
(a) 5 (b) 1.25 (c) 4 (d) 2.5

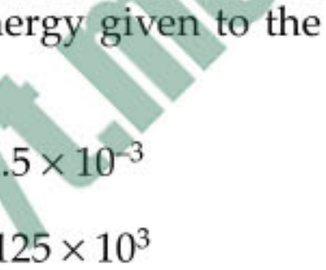
2. A number of condensers, each of the capacitance 1 μF and each one of which gets punctured if a potential difference just exceeding 500 V is applied, are provided. An arrangement suitable for giving capacitance of 2 μF across which 3000 V may be applied requires at least
(a) 6 component capacitors
(b) 12 component capacitors
(c) 72 component capacitors
(d) 2 component capacitors

3. A body of mass 1 g and carrying a charge 10^{-8} C passes from two points P and Q. P and Q are at electric potentials 600 V and 0 V respectively. The velocity of the body at Q is 20 cm s^{-1}. Its velocity in m s^{-1} at P is
(a) $\sqrt{0.028}$ (b) $\sqrt{0.056}$ (c) $\sqrt{0.56}$ (d) $\sqrt{5.6}$

4. A parallel plate capacitor of capacity 100 μF is charged by a battery of 50 volts. The battery remains connected and if the plates of the capacitor are separated so that the distance between them becomes double the original distance, the additional energy given to the battery by the capacitor in joules is
(a) $\frac{125\times10^{-3}}{2}$ (b) 12.5×10^{-3}
(c) 1.25×10^{-3} (d) 0.125×10^{3}

5. The electric potential at a point (x, y, z) is given by $V = -x^2y - xz^3 + 4$
The electric field $\vec{E}$ at that point is
(a) $\vec{E} = \hat{i}\,2xy + \hat{j}\,(x^2 + y^2) + \hat{k}\,(3xz - y^2)$
(b) $\vec{E} = \hat{i}\,z^3 + \hat{j}\,xyz + \hat{k}\,z^2$
(c) $\vec{E} = \hat{i}\,(2xy - z^3) + \hat{j}\,xy^2 + \hat{k}\,3z^2x$
(d) $\vec{E} = \hat{i}\,(2xy + z^3) + \hat{j}\,x^2 + \hat{k}\,3xz^2$

6. Two capacitors C_1 and C_2 are connected in a circuit as shown in figure. The potential difference $(V_A - V_B)$ is
(a) 8 V (b) –12 V
(c) –8 V (d) 12 V



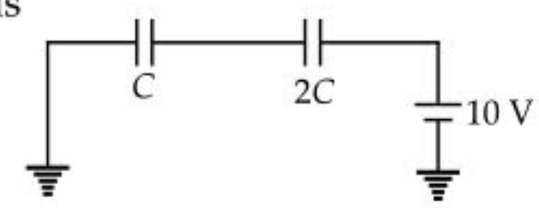
7. An infinite non-conducting sheet has a surface charge density $\sigma = 0.1$ μC m^{-2} on one side. How far apart are equipotential surfaces whose potentials differ by 50 volt?
(a) 8.86 mm (b) 8.8 μm
(c) 8.8 cm (d) 8.8 pm

8. An electric dipole of length 1 cm is placed with the axis making an angle of 30° with an electric field of strength 10^4 N C^{-1}. If it experiences a torque of $10\sqrt{2}$ N m, the potential energy of the dipole is
(a) 0.245 J (b) 2.45 J
(c) 0.0245 J (d) 24.5 J

9. Two point charges A and B of values $+5\times10^{-9}$ C and $+3\times10^{-9}$ C are kept 6 cm apart in air. When the charge B is moved by 1 cm towards charge A, then work done is equal to
(a) 4.5×10^{-6} J (b) 4.5×10^{-7} J
(c) 3.5×10^{-7} J (d) 4.5×10^{-8} J

10. Two spherical conductors A and B of radii 1 mm and 2 mm are separated by a distance of 5 cm and are uniformly charged. If the spheres are connected by a conducting wire, then in equilibrium position, the ratio of the magnitude of electric fields at the surface of the spheres A and B is
(a) 1 : 4 (b) 4 : 1 (c) 1 : 2 (d) 2 : 1

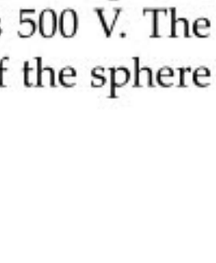
11. In the circuit shown, $C = 6$ μF. The charge stored in the capacitor of capacity C is
(a) zero
(b) 90 μC
(c) 40 μC
(d) 60 μC



12. The electric potential on the surface of a sphere of radius R due to a charge 3×10^{-6} C is 500 V. The intensity of electric field on the surface of the sphere in (N C^{-1}) is
(a) < 10 (b) > 20
(c) between 10 and 20 (d) < 5

13. Two identical capacitors have the same capacitance C. One of them is charged to a potential V_1 and the other to V_2. The negative ends of the capacitors are connected together. When the positive ends are also connected, the decrease in energy of the combined system is
(a) $\frac{1}{4}C(V_1^2 - V_2^2)$ (b) $\frac{1}{4}C(V_1^2 + V_2^2)$
(c) $\frac{1}{4}C(V_1 - V_2)^2$ (d) $\frac{1}{4}C(V_1 + V_2)^2$

14. A parallel plate air capacitor has a capacitance C. When it is half filled with a dielectric of dielectric constant 5 as shown in figure, the percentage increase in the capacitance will be
(a) 400% (b) 66.6%
(c) 33.3% (d) 200%.



15. A spherical droplet having a potential of 2.5 V is obtained as result of merging of 125 identical droplets. Find the potential of the constituent droplet
(a) 0.4 V (b) 0.5 V (c) 0.2 V (d) 0.1 V

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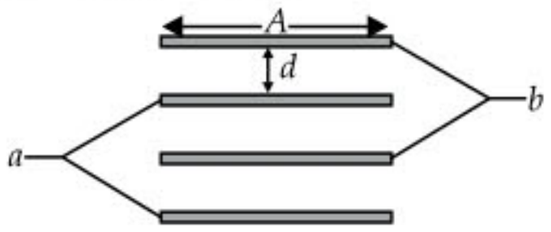
16. Two capacitors, one 4 pF and the other 6 pF, connected in parallel are charged by a 100 V battery. The energy stored in the capacitor is

(a) 1.2×10^{-8} J (b) 2.4×10^{-8} J
(c) 5.0×10^{-8} J (d) 1.2×10^{-6} J

17. The mutual electrostatic potential energy between two protons which are at a distance of 9×10^{-15} m, in $_{92}U^{235}$ nucleus is

(a) 1.56×10^{-14} J (b) 5.5×10^{-14} J
(c) 2.56×10^{-14} J (d) 4.56×10^{-14} J

18. In figure, four parallel capacitors of equal area A and spacing d are arranged, then effective capacitance between points a and b is



(a) $\frac{\varepsilon_0 A}{d}$ (b) $\frac{2\varepsilon_0 A}{d}$ (c) $\frac{3\varepsilon_0 A}{d}$ (d) $\frac{4\varepsilon_0 A}{d}$

19. How much work is required to carry a 6 μC charge from the negative terminal to the positive terminal of a 9 V battery?

(a) 54×10^{-3} J (b) 54×10^{-6} J
(c) 54×10^{-9} J (d) 54×10^{-12} J

20. A 4 μF capacitor is charged to 400 V. If its plates are joined through a resistance of 2 kΩ, then heat produced in the resistance is

(a) 0.16 J (b) 0.32 J (c) 0.64 J (d) 1.28 J

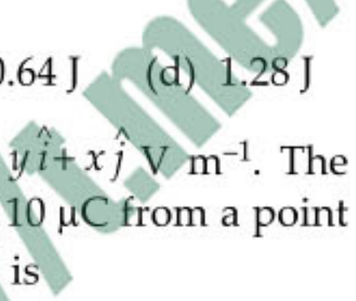
21. An electric field is given by $\vec{E} = y\hat{i} + x\hat{j}$ V m^{-1}. The work done in moving a charge of 10 μC from a point $\vec{r}_1 = 3\hat{i} + 4\hat{j}$ to another $\vec{r}_2 = 2\hat{i} + 6\hat{j}$ is

(a) $10\sqrt{5}$ J (b) $-10\sqrt{5}$ J
(c) $10\sqrt{2} \times 10^{-6}$ J (d) zero

22. A 4 μF capacitor is charged by a 200 V supply. It is then disconnected from the supply and is connected to another uncharged 2 μF capacitor. The energy lost in the process is

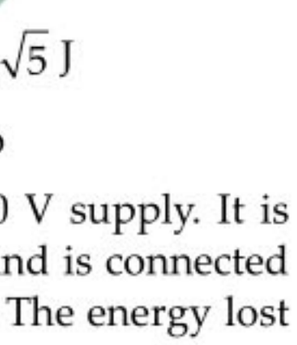
(a) 3×10^{-2} J (b) 3×10^{2} J
(c) 2.67×10^{-2} J (d) 3.8×10^{2} J

23. What is the potential difference across 3 μF capacitor in the circuit shown in the figure?



(a) 6 V
(b) 2 V
(c) 4 V
(d) 16 V

24. Five capacitors each of capacitance value C are connected as shown in the figure. The ratio of capacitance between P and R and the capacitance between P and Q is

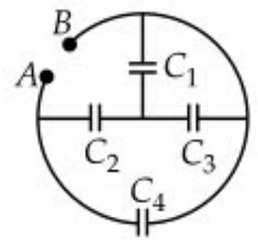


(a) 3 : 1 (b) 5 : 2
(c) 2 : 3 (d) 1 : 1

25. Four point charges $-Q$, $-q$, $2q$ and $2Q$ are placed, one at each corner of the square. The relation between Q and q for which the potential at the centre of the square is zero is

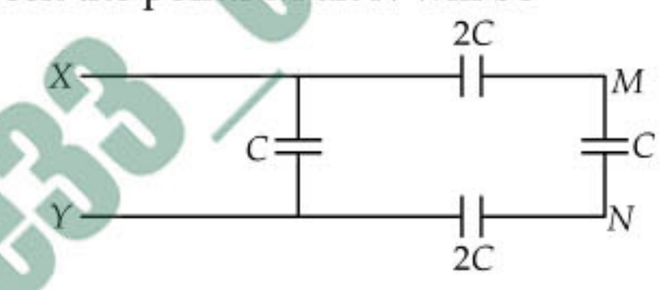
(a) $Q = -q$ (b) $Q = -\frac{1}{q}$
(c) $Q = q$ (d) $Q = \frac{1}{q}$

26. In the arrangement of capacitors shown in figure, each capacitor is of 9 μF, then the equivalent capacitance between the points A and B is



(a) 9 μF (b) 18 μF
(c) 4.5 μF (d) 15 μF

27. In the adjoining figure the potential difference between X and Y is 60 V. The potential difference between the points M an N will be



(a) 10 V (b) 15 V (c) 20 V (d) 30 V

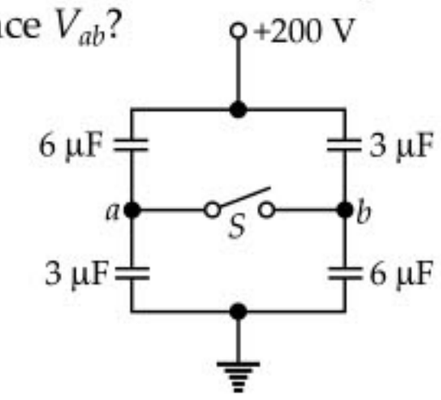
28. The electrostatic potential inside a charged spherical ball is given by $\phi = ar^2 + b$ where r is the distance from the centre; a, b are constants.
Then the charge density inside the ball is

(a) $-6a\varepsilon_0 r$ (b) $-24\pi a\varepsilon_0 r$
(c) $-6a\varepsilon_0$ (d) $-24\pi a\varepsilon_0$

29. A 4 μF capacitor is charged by a 200 V battery. It is then disconnected from the supply and is connected to another uncharged 2 μF capacitor. During the process, loss of energy is

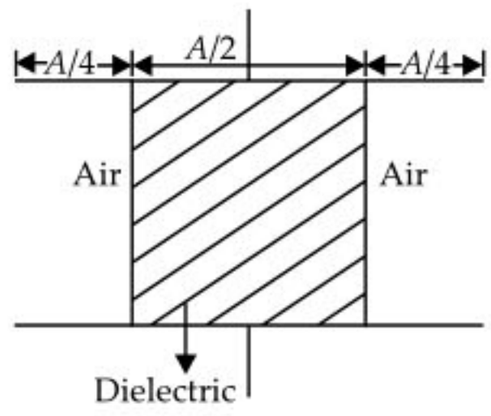
(a) 3.43×10^{-2} J (b) 2.67×10^{-2} J
(c) 2.67×10^{-4} J (d) 3.43×10^{-4} J

30. The capacitors in figure are initially uncharged, and are connected as in the figure with switch S open. What is the potential difference V_{ab}?



(a) 100 V
(b) $\frac{200}{3}$ V
(c) $\frac{100}{3}$ V
(d) 50 V

31. Consider a parallel plate capacitor of capacity 10 μF filled with air. When the gap between the plates is filled partly with a dielectric of dielectric constant 4, as shown in figure. The new capacity of the capacitor is (A is the area of plates)



(a) 20 μF (b) 40 μF (c) 2.5 μF (d) 25 μF

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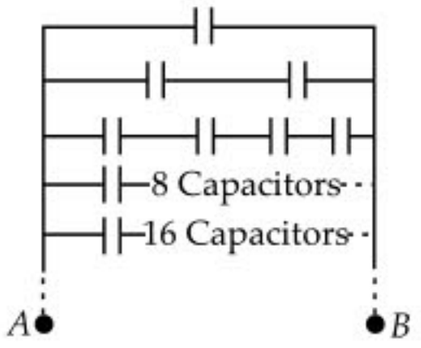
32. Two charges $+q$ and $-q$ are kept apart. Then at any point on the right bisector of line joining the two charges
(a) the electric field strength is zero.
(b) the electric potential is zero.
(c) both electric potential and electric field strength are zero.
(d) both electric potential and electric field strength are non-zero.

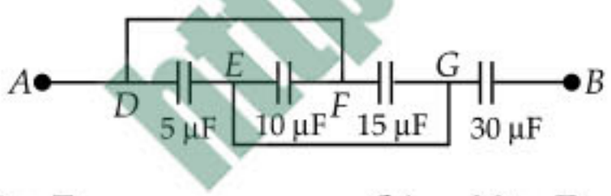
33. The plates of a parallel plate capacitor are charged upto 200 V. A dielectric slab of thickness 4 mm is inserted between its plates. Then, to maintain the same potential difference between the plates of the capacitor, the distance between the plates is increased by 3.2 mm. The dielectric constant of the dielectric slab is
(a) 1 (b) 4
(c) 5 (d) 6

34. An infinite number of identical capacitors each of capacitance 1 μF are connected as shown in figure. Then the equivalent capacitance between A and B is



(a) 1 μF (b) 2 μF
(c) $\frac{1}{2}$ μF (d) ∞

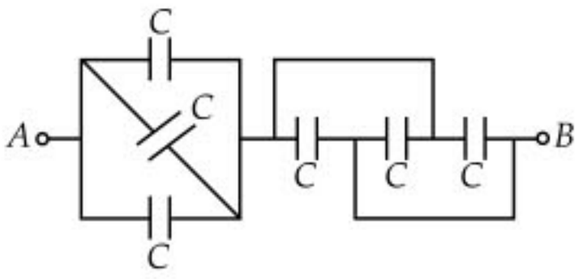
35. The equivalent capacitance between the points A and B is



(a) 15 mF (b) 30 mF
(c) 60 mF (d) 45 mF

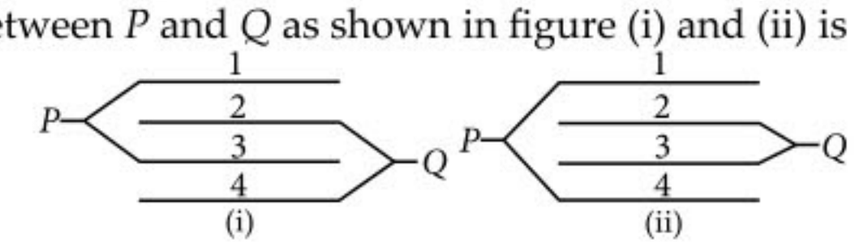
36. Three capacitors of capacitances C(μF) are connected in parallel to which a capacitor of capacitance C is connected in series. Effective capacitance is 3.75 μF, then capacitance of each capacitor is
(a) 4 μF (b) 5 μF
(c) 6 μF (d) 8 μF

37. In the given figure, the equivalent capacitance between points A and B is



(a) 1.5C (b) 2C
(c) 3C (d) 6C

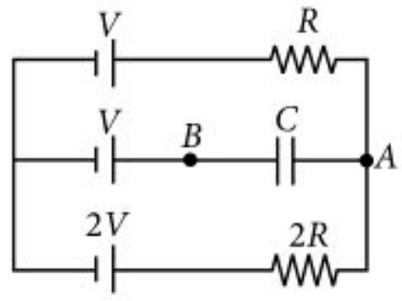
38. The following arrangement consists of four plates. The area of each plate is A and separation between successive plates is d. The ratio of effective capacitance between P and Q as shown in figure (i) and (ii) is



(a) $\frac{3}{2}$ (b) $\frac{2}{3}$
(c) 1 (d) $\frac{4}{3}$

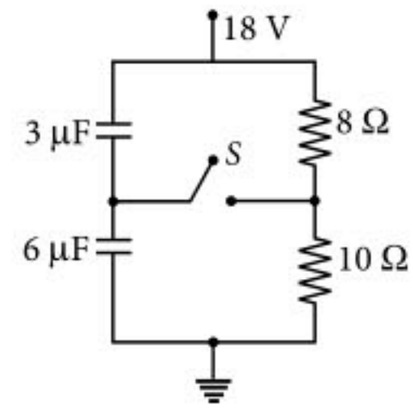
39. The radius of the dome of a Van de Graaff generator is $r = 0.13$ m. Assume that the maximum magnitudes for the charge (Q_{max}) and potential (V_{max}) of the dome are determined by the electric strength of the surrounding air ($E_{max} = 3 \times 10^6$ V m^{-1}). The value of Q_{max} and V_{max} are
(a) 10 μC and 10 kV (b) 15 μC and 400 kV
(c) 6 μC and 400 kV (d) 6 μC and 100 kV

40. In the given circuit as shown in figure, with steady current, the potential difference across the capacitor must be



(a) V (b) $\frac{V}{2}$
(c) $\frac{V}{3}$ (d) $\frac{2V}{3}$

41. In the figure shown, the potential drop across 3 μF capacitor when switch S is open and switch S is closed is



(a) 9 V, 8 V (b) 9 V, 9 V
(c) 6 V, 8 V (d) 12 V, 8 V

42. A 600 pF capacitor is charged by 200 V supply. It is then disconnected from the supply and is connected to another 300 pF capacitor. The electrostatic energy lost in the process is
(a) 0 (b) 4×10^{-6} J
(c) 6×10^{-6} J (d) 8×10^{-6} J

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43. The capacitance of a parallel plate capacitor with air as medium is 3 μF. With the introduction of a dielectric medium between the plates, the capacitance becomes 15 μF. The permittivity of the medium is

(a) $5\ C^2\ N^{-1}\ m^{-2}$

(b) $15\ C^2\ N^{-1}\ m^{-2}$

(c) $0.44 \times 10–10\ C^2\ N^{-1}\ m^{-2}$

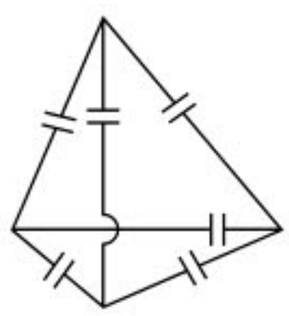
(d) $8.854 \times 10^{-11}\ C^2\ N^{-1}\ m^{-2}$

44. Two positive charges of magnitude q are placed at the ends of a side (side 1) of square of side $2a$. Two negative charges of the same magnitude are kept at the other corners. Starting from rest, if a charge Q moves from the middle of side 1 to the centre of square, its kinetic energy at the centre of square is

(a) $\frac{1}{4\pi\varepsilon_0}\frac{2qQ}{a}\left(1-\frac{1}{\sqrt{5}}\right)$ (b) zero

(c) $\frac{1}{4\pi\varepsilon_0}\frac{2qQ}{a}\left(1+\frac{1}{\sqrt{5}}\right)$ (d) $\frac{1}{4\pi\varepsilon_0}\frac{2qQ}{a}\left(1-\frac{2}{\sqrt{5}}\right)$

45. If the capacitance of each capacitor is C, then effective capacitance of the shown network across any two junctions is



(a) $2C$ (b) C

(c) $\frac{C}{2}$ (d) $5C$

DAY 16 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ

Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____

(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (a) : Here, $t = 2$ mm, $x = 1.6$ mm
As potential difference remains the same, capacity must remain the same.

$$\therefore \quad x = t\left(1 - \frac{1}{K}\right)$$

$1.6 = 2\left(1 - \frac{1}{K}\right)$, which gives $K = 5$

2. (c) : Minimum number of condensers in each row = 3000/500 = 6.
If C_s is capacity of 6 condensers in a row,

$$\frac{1}{C_s} = \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} = 6$$

or $\quad C_s = \frac{1}{6}\mu F$

Let there be m such rows in parallel.
Total capacity = $m \times C_s$

or $\quad 2 = m \times \frac{1}{6} \quad \therefore \quad m = 12$

3. (a) : Work done = gain in K.E.

$$q\Delta V = \frac{1}{2}m(v_Q^2 - v_P^2)$$

$$10^{-8} \times (600 - 0) = \frac{1}{2} \times 10^{-3}[(20 \times 10^{-2})^2 - v_P^2]$$

Solving, we get $v_p = \sqrt{0.028}$ m s^{-1}

4. (a) : Initial energy

$$U_1 = \frac{1}{2}CV^2 = \frac{1}{2} \times 100 \times 10^{-6} \times (50)^2$$
$$= 125 \times 10^{-3} \text{ J}$$

When the distance is doubled, the capacitance decreases to 1/2, *i.e.*, $C' = 50$ μF
$\therefore$ Final energy

$$U_2 = \frac{1}{2}C'V^2 = \frac{1}{2} \times 50 \times 10^{-6} \times (50)^2$$
$$= \frac{125 \times 10^{-3}}{2}$$

Additional energy, $U = U_1 - U_2 = \frac{125 \times 10^{-3}}{2}$ J

5. (d) : The electric potential at a point,
$V = -x^2y - xz^3 + 4$.

The field $\vec{E} = -\vec{\nabla}V = -\left(\frac{\partial V}{\partial x}\hat{i} + \frac{\partial V}{\partial y}\hat{j} + \frac{\partial V}{\partial z}\hat{k}\right)$

$$\therefore \quad \vec{E} = \hat{i}(2xy + z^3) + \hat{j}x^2 + \hat{k}(3xz^2)$$

6. (c) : As C_1 and C_2 are connected in parallel,

$$\therefore \quad \frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{2} + \frac{1}{4} = \frac{3}{4}$$

$$C_S = \frac{4}{3}\mu F$$

Charge on each capacitor, $Q = C_S \times V$

$$= \frac{4}{3} \times 12 = 16\,\mu C$$

$$V_A - V_B = -\frac{Q}{C_1} = -\frac{16}{2} = -8 \text{ V}$$

7. (a) : Here, $\sigma = 0.1\ \mu C\ m^{-2} = 0.1 \times 10^{-6}$ C m^{-2}
$dr = ?$, $dV = 50$ V

$$E = \frac{\sigma}{2\varepsilon_0} = \frac{dV}{dr}$$

$$dr = \frac{2\varepsilon_0 dV}{\sigma} = \frac{2 \times 8.86 \times 10^{-12} \times 50}{0.1 \times 10^{-6}}$$

$= 8.86 \times 10^{-3}$ m = 8.86 mm

8. (d): Here, $\tau = pE \sin\theta$

$$10\sqrt{2} = p \times 10^4 \sin 30° = 10^4 \times \frac{p}{2}$$

$$p = \frac{20\sqrt{2}}{10^4} = 2\sqrt{2} \times 10^{-3}$$

P.E. = $pE\cos\theta$

$$= 2\sqrt{2} \times 10^{-3} \times 10^4 \cos 30° = 20\sqrt{2} \times \frac{\sqrt{3}}{2}$$

$= 10\sqrt{6} = 10 \times 2.45$ J = 24.5 J

9. (b) : $q_A = +5 \times 10^{-9}$ C, $q_B = 3 \times 10^{-9}$ C
Initial distance between the charges (r_1) = 6×10^{-2} m
Final distance between the charges (r_2) = 5×10^{-2} m
In moving the charge,
Work done = Final P.E. – Initial P.E.

$$= 9 \times 10^9 \times 5 \times 10^{-9} \times 3 \times 10^{-9} \times \left(\frac{1}{5 \times 10^{-2}} - \frac{1}{6 \times 10^{-2}}\right)$$

$$= 135 \times 10^{-9} \times \frac{1}{30 \times 10^{-2}}$$

$= 4.5 \times 10^{-7}$ J

10. (d) : When joined by a wire, the two spheres attain common potential V.

$\therefore$ Intensity, $E_A = \frac{1}{4\pi\varepsilon_0}\frac{q_A}{R_A^2}$

$$= \frac{C_A V}{4\pi\varepsilon_0 R_A^2} = \frac{4\pi\varepsilon_0 R_A V}{4\pi\varepsilon_0 R_A^2} = \frac{V}{R_A}$$

Similarly, $E_B = \frac{V}{R_B}$

$$\therefore \quad \frac{E_A}{E_B} = \frac{R_B}{R_A} = \frac{2}{1}$$

11. (c) : Both the capacitors are in series. Therefore, charge stored on them will be same.

Net capacity = $\frac{C(2C)}{C + 2C} = \frac{2}{3}C = \frac{2}{3} \times 6\,\mu F = 4\,\mu F$

Potential difference = 10 V
$\therefore \quad q = CV = 40\ \mu C$

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12. (a) : Here, $V = \frac{q}{4\pi\varepsilon_0 R} = 500;\ R = \frac{q}{4\pi\varepsilon_0(500)}$

$$E = \frac{q}{4\pi\varepsilon_0 R^2} = \frac{q[4\pi\varepsilon_0(500)]^2}{4\pi\varepsilon_0 \times q^2} = \frac{4\pi\varepsilon_0 \times 25\times10^4}{q}$$

$$E = \frac{25\times10^4}{9\times10^9\times3\times10^{-6}} = 9.26\ \text{N C}^{-1}$$

13. (c) : The initial energy of the system,

$$U_i = \frac{1}{2}CV_1^2 + \frac{1}{2}CV_2^2 = \frac{1}{2}C\left(V_1^2 + V_2^2\right)$$

When the capacitors are joined, they reach a common potential V.

$$V = \frac{q_1 + q_2}{C_1 + C_2} = \frac{CV_1 + CV_2}{C + C} = \frac{V_1 + V_2}{2}$$

The final energy of the system,

$$U_f = \frac{1}{2}(C + C)V^2 = \frac{1}{2}(2C)V^2$$

Decrease in energy,

$$U_i - U_f = \frac{1}{2}C\left(V_1^2 + V_2^2\right) - \frac{1}{2}(2C)\left(\frac{V_1 + V_2}{2}\right)^2$$

$$= \frac{1}{4}C\left(V_1 - V_2\right)^2$$

14. (b) : $C = \frac{\varepsilon_0 A}{d}$ ...(i)

When it is half filled with dielectric of $K = 5$, its capacitance becomes C_s which is series combination of

$$C_1 = \frac{K\varepsilon_0 A}{d/2} = \frac{\varepsilon_0 A}{d/2K} = \frac{\varepsilon_0 A}{d/10}$$

and $C_2 = \frac{\varepsilon_0 A}{d/2}$

$$\therefore\quad \frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{d/10}{\varepsilon_0 A} + \frac{d/2}{\varepsilon_0 A} = \frac{(3d/5)}{\varepsilon_0 A}$$

$$\Rightarrow\quad C_s = \frac{5}{3}\frac{\varepsilon_0 A}{d} = \frac{5C}{3} \qquad \text{(Using (i))}$$

Percentage increase in capacitance

$$= \frac{C_s - C}{C}\times100$$

$$= \frac{\frac{5}{3}C - C}{C}\times100 = \frac{2}{3}\times100 = 66.6\%$$

15. (d) : $V_0 = \frac{q}{4\pi\varepsilon_0 r}$

$$\frac{4}{3}\pi R^3 = 125\times\frac{4}{3}\pi r^3 \ \text{ or } \ R = 5r$$

$$V = 2.5 = \frac{125q}{4\pi\varepsilon_0(5r)}$$

$$\text{or}\quad 2.5 = \frac{125}{5}\times\frac{q}{4\pi\varepsilon_0 r}$$

$$\text{or}\quad 2.5 = 25\times V_0$$

$$\therefore\quad V_0 = \frac{2.5}{25} = 0.1\ \text{V}$$

16. (c) : The energy stored in capacitor is given by

$$U = \frac{1}{2}CV^2 \qquad ...(i)$$

Resultant capacitance

$$C = C_1 + C_2 = 4 + 6 = 10\ \text{pF}$$

$$\therefore\quad U = \frac{1}{2}\times10\times10^{-12}\times(100)^2\ (\because\ 1\ \text{pF} = 10^{-12}\ \text{F})$$

$$= 5\times10^{-8}\ \text{J}$$

17. (c) : Electrostatic potential energy

$$U = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_1 q_2}{r}$$

Here, $q_1 = q_2 = 16\times10^{-19}\ \text{C}$ and $r = 9\times10^{-15}\ \text{m}$

$$\therefore\quad U = \frac{9\times10^9\times1.6\times10^{-19}\times1.6\times10^{-19}}{9\times10^{-15}} = 2.56\times10^{-14}\ \text{J}$$

18. (c)

19. (b) : Using $W = qV$

$$= 6\times10^{-6}\times9 = 54\times10^{-6}\ \text{J}$$

20. (b) : Heat produced = energy stored

$$= \frac{1}{2}CV^2 = \frac{1}{2}\times4\times10^{-6}\times400\times400 = 0.32\ \text{J}$$

21. (d) : $V_2 - V_1 = -\int_{\vec{r}_1}^{\vec{r}_2}\vec{E}\cdot d\vec{r}$

$$= -\int_{(3,4)}^{(2,6)}\left(y\,\hat{i} + x\,\hat{j}\right)\cdot\left(dx\,\hat{i} + dy\,\hat{j}\right)$$

$$= -\int_{(3,4)}^{(2,6)} ydx + xdy = -\int_{(3,4)}^{(2,6)} d(xy)$$

$$= -\left[xy\right]_{(3,4)}^{(2,6)} = -[2\times6 - 3\times4] = 0\ \text{V}$$

Work done, $W = q\,(V_2 - V_1) = \text{zero}$

22. (c) : Initial energy,

$$U_1 = \frac{1}{2}C_1V_1^2 = \frac{1}{2}\times(4\times10^{-6})(200)^2 = 8\times10^{-2}\ \text{J}$$

Common potential

$$V = \frac{q_1 + q_2}{C_1 + C_2} = \frac{4\times200 + 0}{4 + 2} = \frac{400}{3}\ \text{V}$$

Final energy, $U_2 = \frac{1}{2}(C_1 + C_2)V^2$

$$= \frac{1}{2}\times6\times10^{-6}\times\left(\frac{400}{3}\right)^2 = 5.33\times10^{-2}\ \text{J}$$

Loss of energy = $U_1 - U_2 = 2.67\times10^{-2}\ \text{J}$

23. (c) : Let the charge in the loop be q.

$$\frac{q}{2\times10^{-6}} - 16 + \frac{q}{3\times10^{-6}} + 6 = 0$$

$$\frac{5q}{6\times10^{-6}} = 10 \ \text{ or } \ q = 12\ \mu\text{C}$$

The potential difference across 3 μF capacitor is

$$= \frac{q}{3\ \mu\text{F}} = \frac{12\ \mu\text{C}}{3\ \mu\text{F}} = 4\ \text{V}$$

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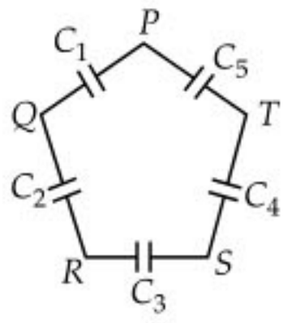
24. (c) : Between P and Q, a capacitor C_1 and a series combination of C_2, C_3, C_4, C_5 are connected in parallel.

$$\therefore \quad \frac{1}{C_s}=\frac{1}{C_2}+\frac{1}{C_3}+\frac{1}{C_4}+\frac{1}{C_5}$$

$$=\frac{1}{C}+\frac{1}{C}+\frac{1}{C}+\frac{1}{C}=\frac{4}{C}$$

or $\quad C_s=\frac{C}{4}$



The equivalent capacitance between P and Q is

$$C'=C_1+C_s=C+\frac{C}{4}=\frac{5C}{4}$$

Between P and R, a series combination of C_1, C_2 and a series combination of C_3, C_4, C_5 are connected in parallel.

$$\therefore \quad \frac{1}{C_s'}=\frac{1}{C_1}+\frac{1}{C_2}=\frac{1}{C}+\frac{1}{C}=\frac{2}{C} \quad \text{or} \quad C_s'=\frac{C}{2}$$

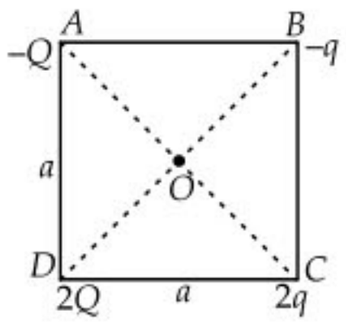
and $\quad \frac{1}{C_s''}=\frac{1}{C_3}+\frac{1}{C_4}+\frac{1}{C_5}=\frac{1}{C}+\frac{1}{C}+\frac{1}{C}=\frac{3}{C}$ or $C_s''=\frac{C}{3}$

The equivalent capacitance between P and R is

$$C''=C_s'+C_s''=\frac{C}{2}+\frac{C}{3}=\frac{5C}{6}$$

$$\therefore \quad \frac{C''}{C'}=\frac{\frac{5C}{6}}{\frac{5C}{4}}=\frac{2}{3}$$

25. (a) :



Let a be the side length of the square $ABCD$.

$$\therefore \quad AC=BD=\sqrt{a^2+a^2}=a\sqrt{2}$$

$$OA=OB=OC=OD=\frac{a\sqrt{2}}{2}=\frac{a}{\sqrt{2}}$$

Potential is a scalar quantity.

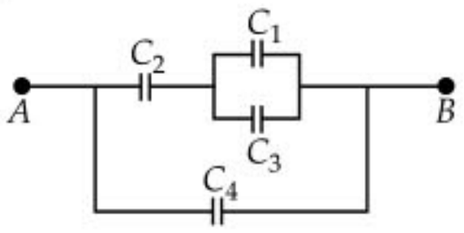
Potential at the centre O due to given charge configuration is

$$V=\frac{1}{4\pi\varepsilon_0}\left[\frac{(-Q)}{\left(\frac{a}{\sqrt{2}}\right)}+\frac{(-q)}{\left(\frac{a}{\sqrt{2}}\right)}+\frac{(2q)}{\left(\frac{a}{\sqrt{2}}\right)}+\frac{2Q}{\left(\frac{a}{\sqrt{2}}\right)}\right]=0$$

$$\Rightarrow \quad -Q-q+2q+2Q=0$$

or $\quad Q+q=0$ or $Q=-q$

26. (d) : The equivalent circuit as shown in the figure.



Capacitors C_1 and C_3 are connected in parallel, so their equivalent capacitance is

$$\therefore \quad C' = C_1 + C_3 = 9 + 9 = 18\ \mu F$$

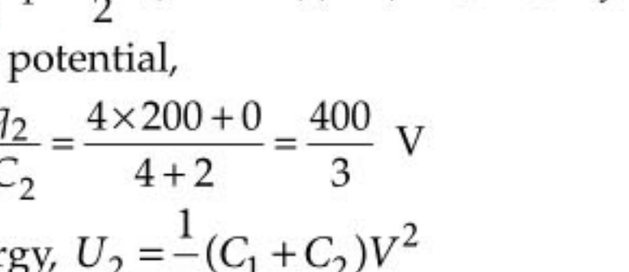
This is in series with capacitor C_2, so their equivalent capacitance is

$$C''=\frac{C_2\times C'}{C_2+C'}=\frac{9\ \mu F\times 18\ \mu F}{(9+18)\ \mu F}=6\ \mu F$$

The equivalent capacitance between A and B is

$$\therefore \quad C_{AB}=C''+C_4=6\ \mu F+9\ \mu F=15\ \mu F$$

27. (d) :



In the given figure, capacitors $2C$, C (between M and N) and $2C$ are in series. If Q is the charge on each of these capacitors, then

$$60=\frac{Q}{2C}+\frac{Q}{C}+\frac{Q}{2C}=\frac{2Q}{C}$$

$$Q=30C$$

Potential difference between M and N is

$$=\frac{Q}{C}=\frac{30C}{C}=30\ V$$

28. (c)

29. (b) : Initial energy,

$$U_1=\frac{1}{2}C_1V_1^2=\frac{1}{2}\times(4\times10^{-6})(200)^2=8\times10^{-2}\ J$$

Common potential,

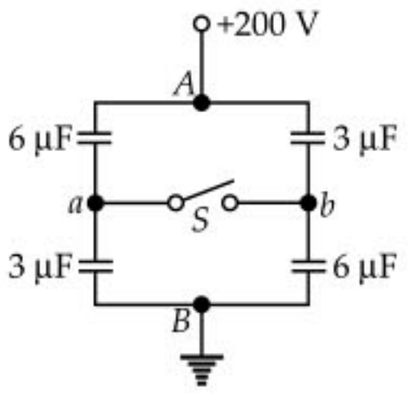
$$V=\frac{q_1+q_2}{C_1+C_2}=\frac{4\times200+0}{4+2}=\frac{400}{3}\ V$$

Final energy, $U_2=\frac{1}{2}(C_1+C_2)V^2$

$$U_2=\frac{1}{2}\times6\times10^{-6}\times\left(\frac{400}{3}\right)^2=5.33\times10^{-2}\ J$$

Loss of energy $= U_1 - U_2 = 2.67\times10^{-2}\ J$

30. (b) :



$$V_A - V_a = \frac{200\times3}{6+3}\ V=\frac{200\times3}{9}\ V=\frac{200}{3}\ V$$

$$V_A - V_b = \frac{200\times6}{3+6}\ V=\frac{200\times6}{9}\ V=\frac{400}{3}\ V$$

$$\therefore \quad V_{ab}=V_a-V_b=V_A-V_b-(V_A-V_a)$$

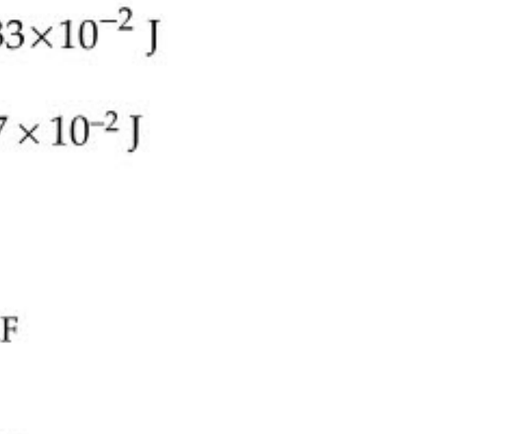
$$=\frac{400}{3}\ V-\frac{200}{3}\ V=\frac{200}{3}\ V$$

31. (d) : Capacitance of a parallel plate capacitor is

$$C=\frac{\varepsilon_0 A}{d}=10\ \mu F$$

Capacitance of I part is

$$C_1=\frac{\varepsilon_0\frac{A}{4}}{d}=\frac{\varepsilon_0 A}{4d}$$



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Capacitance of II[nd] part is

$$C_2 = \frac{K\varepsilon_0 \frac{A}{2}}{d} = \frac{K\varepsilon_0 A}{2d} = \frac{4\varepsilon_0 A}{2d}$$

Capacitance of III[rd] part is

$$C_3 = \frac{\varepsilon_0 \frac{A}{4}}{d} = \frac{\varepsilon_0 A}{4d}$$

$\because$ C_1, C_2 and C_3 are in parallel

$\therefore$ The new capacitance of the capacitor is

$= C_1 + C_2 + C_3$

$$= \frac{\varepsilon_0 A}{4d} + \frac{4\varepsilon_0 A}{2d} + \frac{\varepsilon_0 A}{4d} = \frac{\varepsilon_0 A + 8\varepsilon_0 A + \varepsilon_0 A}{4d}$$

$$= \frac{10\varepsilon_0 A}{4d} = \frac{10}{4}\left(\frac{\varepsilon_0 A}{d}\right) = \frac{10}{4} \times 10\ \mu F = 25\ \mu F$$

32. (b) **33. (c)**

34. (b) : Capacities of successive rows from top are C, $\frac{C}{2}, \frac{C}{4}, \frac{C}{8}, \frac{C}{16}$ and so on, where $C = 1\ \mu F$

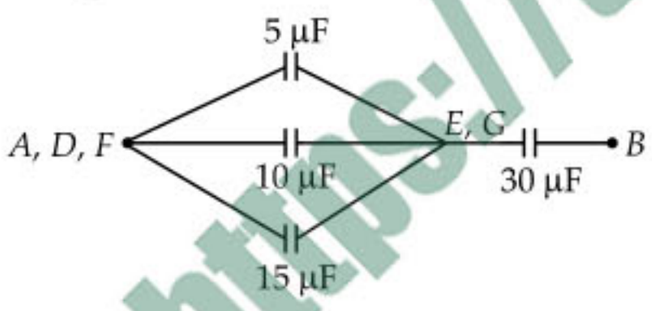
These rows are in parallel. Therefore, the equivalent capacitance between A and B is

$$C_{AB} = 1 + \frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \frac{1}{16} + ...\infty$$

which is geometrical progression

$$C_{AB} = \frac{1}{1 - \frac{1}{2}} = 2\ \mu F$$

35. (a) : The equivalent circuit is as shown in the figure.



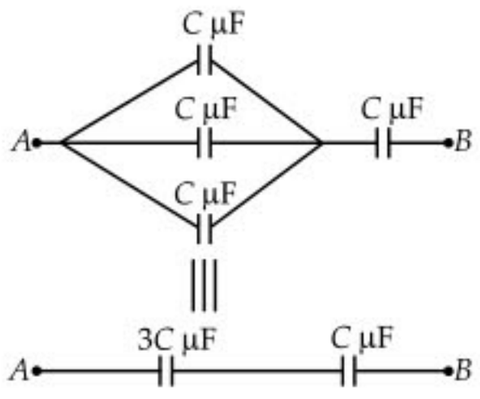
Capacitors of 5 μF, 10 μF and 15 μF are in parallel. Their equivalent capacitance is

Cp = 5 + 10 + 15 = 30 mF

The combination is connected in series with 30 mF capacitor. Therefore, the equivalent capacitance between the points A and B is

$$\frac{1}{C_{AB}} = \frac{1}{30} + \frac{1}{30} = \frac{1}{15} \quad \text{or} \quad C_{AB} = 15\ mF$$

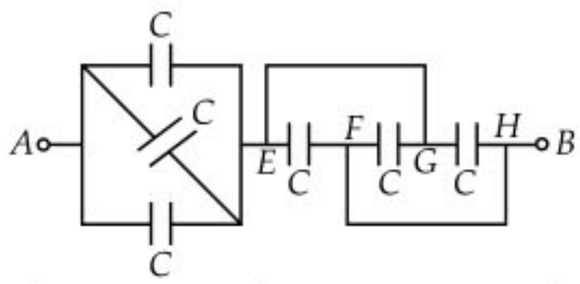
36. (b) : As per question the capacitors are connected as shown in the adjacent figure. Effective capacitance between A and B is



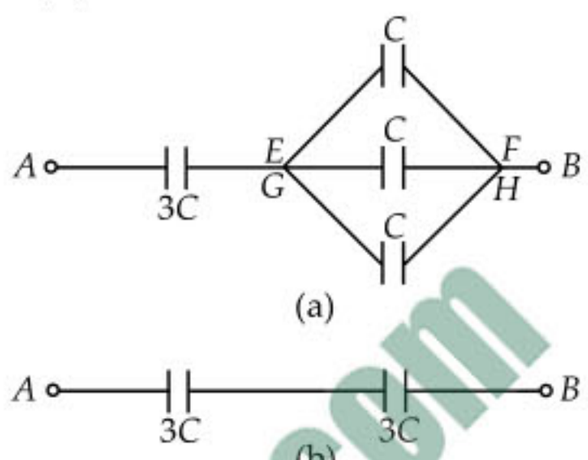
$$C_{eff} = \frac{(3C)(C)}{3C + C} = 3.75\ \mu F$$

or $\frac{3}{4}C = 3.75\ \mu F$ or $C = 5\ \mu F$

37. (a) :



The equivalent circuit diagrams are as shown in the figure (a) and (b).

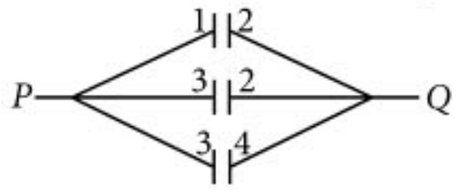


The equivalent capacitance between A and B is

$$\frac{1}{C_{eq}} = \frac{1}{3C} + \frac{1}{3C} \text{ or } \frac{1}{C_{eq}} = \frac{2}{3C} \text{ or } C_{eq} = \frac{3}{2}C = 1.5C$$

38. (a) : For figure (i)

The arrangement will work as a system of three capacitors connected in parallel as shown in the figure.



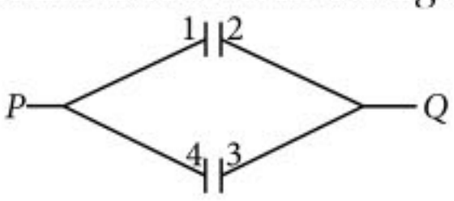
Capacitance of each capacitor, $C = \frac{\varepsilon_0 A}{d}$

The effective capacitance between P and Q is

$$C_1 = 3\frac{\varepsilon_0 A}{d}$$

For figure (ii)

The arrangement will work as a system of two capacitors connected in parallel as shown in the figure.



The effective capacitance between P and Q is

$$C_2 = \frac{2\varepsilon_0 A}{d} \quad \therefore \quad \frac{C_1}{C_2} = \frac{3}{2}$$

39. (c) : Considering the dome as an isolated spherical conductor, we have

$$E = \frac{|Q|}{4\pi\varepsilon_0 r^2} = \frac{|V|}{r}$$

Therefore, the maximum charge Q_{max} and the maximum potential V_{max} for the conducting shpere surrounding by an insulator with dielectric strength E_{max} are

$$Q_{max} = E_{max} 4\pi\varepsilon_0 r^2$$

$$= \frac{(3 \times 10^6)(0.13)^2}{9 \times 10^9} = 6\ \mu C$$

and $V_{max} = E_{max} r = (3 \times 10^6)(0.13) \approx 400\ kV$

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40. (c) : Current inside the circuit

$$I = \frac{V}{3R}$$ (At steady state capacitor is open)

$\therefore$ P.D. across the capacitor

$$V_B - V_A = (V - \frac{V}{3R} \times 2R) = \frac{V}{3}$$

41. (d) : When switch is open 18 V is applied across 6 μF and 3 μF capacitor

Voltage across 3 μF is given by

$$V_1 = \frac{18 \times 6}{6+3} = 12 \text{ V}$$

When the switch is closed potential drop across 8 Ω resistor is the potential drop across 3 μF capacitor. Potential drop across 8 Ω.

$$= \frac{18 \times 8}{10+8} = 8 \text{ V}$$

42. (b) : Here, $C_1 = 600 \text{ pF} = 600 \times 10^{-12} \text{ F}$

$C_2 = 300 \text{ pF} = 300 \times 10^{-12} \text{ F}$

$V_1 = 200 \text{ V}$

Initial electrostatic energy stored in C_1 is

$$U_i = \frac{1}{2} C_1 V_1^2$$

$$= \frac{1}{2} \times (600 \times 10^{-12}) \times (200)^2 = 12 \times 10^{-6} \text{ J}$$

Charge on the 600 μF capacitor, $Q_1 = C_1 V_1$

$= 600 \times 10^{-12} \times 200 \text{ C}$

When 600pF capacitor is disconnected from the supply and is connected to another uncharged 300pF capacitor, the charge is shared between them till both attain the common potential which is given by

$\therefore$ Common potential, $V = \frac{Q_1 + Q_2}{C_1 + C_2}$

$$V = \frac{C_1 V_1 + 0}{C_1 + C_2} = \frac{600 \times 10^{-12} \times 200}{(600+300) \times 10^{-12}} = \frac{400}{3} \text{ V}$$

Final electrostatic energy in both capacitors,

$$U_f = \frac{1}{2}(C_1 + C_2) V^2$$

$$= \frac{1}{2}[(600+300) \times 10^{-12})] \times \left(\frac{400}{3}\right)^2$$

$$= 8 \times 10^{-6} \text{ J}$$

Loss of electrostatic energy $= U_i - U_f$

$= (12 - 8) \times 10^{-6} \text{ J} = 4 \times 10^{-6} \text{ J}$

43. (c) : Capacitance of a parallel plate capacitor with air is $C = \frac{\varepsilon_0 A}{d}$

Capacitance of the same parallel plate capacitor with the introduction of a dielectric medium is

$$C' = \frac{K\varepsilon_0 A}{d}$$

where K is the dielectric constant of a medium

or $\frac{C'}{C} = K$ or $K = \frac{15}{3} = 5$ or $K = \frac{\varepsilon}{\varepsilon_0}$

or $\varepsilon = K\varepsilon_0 = 5 \times 8.854 \times 10^{-12}$

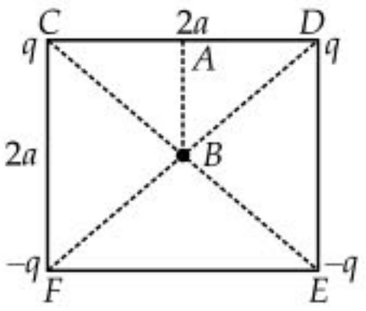
$= 0.4427 \times 10^{-10} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$

44. (a) : Refer figure,

$AC = AD = a$

$$AE = AF = \sqrt{a^2 + (2a)^2}$$

$$= \sqrt{5}\, a$$



$BC = BD = BE = BF = \sqrt{2}\, a$

Potential at point A is

$$V_A = \left(\frac{1}{4\pi\varepsilon_0}\frac{q}{AC} + \frac{1}{4\pi\varepsilon_0}\frac{q}{AD} - \frac{1}{4\pi\varepsilon_0}\frac{q}{AE} - \frac{1}{4\pi\varepsilon_0}\frac{q}{AF}\right)$$

$$= \left(\frac{1}{4\pi\varepsilon_0}\frac{q}{a} + \frac{1}{4\pi\varepsilon_0}\frac{q}{a} - \frac{1}{4\pi\varepsilon_0}\frac{q}{\sqrt{5a}} - \frac{1}{4\pi\varepsilon_0}\frac{q}{\sqrt{5a}}\right)$$

$$V_A = 2\left(\frac{1}{4\pi\varepsilon_0}\frac{q}{a}\right) - 2\left(\frac{1}{4\pi\varepsilon_0}\frac{q}{\sqrt{5}a}\right)$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{2q}{a}\left(1 - \frac{1}{\sqrt{5}}\right)$$

Potential at point B is

$$V_B = \left(\frac{1}{4\pi\varepsilon_0}\frac{q}{BC} + \frac{1}{4\pi\varepsilon_0}\frac{q}{BD} - \frac{1}{4\pi\varepsilon_0}\frac{q}{BE} - \frac{1}{4\pi\varepsilon_0}\frac{q}{BF}\right)$$

$$= \left(\frac{1}{4\pi\varepsilon_0}\frac{q}{\sqrt{2}a} + \frac{1}{4\pi\varepsilon_0}\frac{q}{\sqrt{2}a} - \frac{1}{4\pi\varepsilon_0}\frac{q}{\sqrt{2}a} - \frac{1}{4\pi\varepsilon_0}\frac{q}{\sqrt{2}a}\right)$$

$$V_B = 2\left(\frac{1}{4\pi\varepsilon_0}\frac{q}{\sqrt{2}\,a}\right) - 2\left(\frac{1}{4\pi\varepsilon_0}\frac{q}{\sqrt{2}\,a}\right) = 0$$

$\therefore \quad V_A - V_B = \frac{1}{4\pi\varepsilon_0}\frac{2q}{a}\left(1 - \frac{1}{\sqrt{5}}\right)$

Kinetic energy at the centre of square of charge Q

= Work done on charge Q from A to B is

$$W = Q(V_A - V_B) = \frac{1}{4\pi\varepsilon_0}\frac{2qQ}{a}\left(1 - \frac{1}{\sqrt{5}}\right)$$

45. (a) : The given network is a balanced Wheatstone bridge with one capacitor in parallel with this bridge.

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Current Electricity

Electric Current

Electric current is the rate of flow of electric charge across any cross-section of a conductor.

The current at any time t is given by

$$I = \lim_{\Delta t \to 0} \frac{\Delta q}{\Delta t} = \frac{dq}{dt}$$

If the current is steady *i.e.* it does not change with time, then

$$I = \frac{q}{t}$$

where q is the charge that flows across the area in time t.

The current is same for all cross-sections of a conductor of non-uniform cross-section. Similar to the water flow, charge flows faster where the conductor is smaller in cross-section and slower where the conductor is larger in cross-section, so that charge rate remains unchanged.

Conventionally, the direction of current is taken to be the direction of flow of positive charges. Since electrons are negatively charged, hence their direction will be opposite to that of the conventional current flow.

Current is a scalar quantity as it does not follow the laws of vector addition.

The dimensional formula of current is $[M^0L^0T^0A]$.

The SI unit of current is **ampere** in honor of the French scientist André Marie Ampére. It is denoted by symbol A. It is one of the seven fundamental quantities. It is also a practical unit of current.

$$1\,A = \frac{1\,C}{1\,s}$$

If n particles, each carrying a charge q, pass through a given cross-section in time t, then current

$$I = \frac{nq}{t}$$

As an example, 1 A current is equivalent to flow of 6.25×10^{18} electrons/s.

Current in different materials is due to motion of different charge carriers. Materials along their charge carriers are as shown in the table.

Materials	Type of charge carriers
Metals	Electrons
Vacuum tubes	Electrons
Electrolytes	Positive and negative ions
Semiconductors	Electrons and holes
Ionised gases	Positive ions and electrons

Drift Velocity

It is average uniform velocity acquired by free electrons inside a metal by the application of an electric field which is responsible for current through it. Drift velocity is very small. It is of the order of 10^{-4} m s^{-1} as compared to thermal speed ($\simeq 10^5$ m s^{-1}) of electrons at room temperature.

Drift velocity, $\vec{v}_d = \frac{-e\vec{E}}{m}\tau$

Here τ is relaxation time, e is the charge, m is the mass of an electron and $\vec{E}$ is applied electric field.

The direction of drift velocity for electrons in a metal is opposite to that of applied electric field.

Mobility : Mobility of a charge carrier is defined as drift velocity acquired per unit electric field.

Mobility, $\mu = \frac{v_d}{E}$

$$= \frac{e\tau}{m} = \frac{em\sigma}{mne^2} = \frac{\sigma}{ne}$$

Its unit is $m^2\,V^{-1}\,s^{-1}$ and dimensions are $[M^{-1}T^2A^1]$.

Current density : It is defined as the amount of charge flowing per unit cross sectional area per second

$$i.e.,\ J = \frac{I}{A}$$

Also, $J = nev_d$.

Ohm's Law

It was discovered by German physicist Georg Simon Ohm in 1828. It states that the current (I) flowing through a conductor is directly proportional to the potential difference (V) across the ends of the conductor, provided physical conditions of the conductor such as temperature, mechanical strain etc. are kept constant.

$$V \propto I \quad \text{or} \quad V = RI$$

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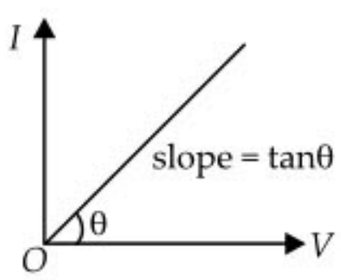
where the constant of proportionality R is called resistance of the conductor.

The graph between potential difference (V) and current (I) through a metallic conductor is a straight line passing through the origin as shown in figure.

The reciprocal of its slope gives its resistance.

$$R = \frac{V}{I} = \frac{1}{\tan\theta \text{ (slope of } I\text{-}V)}$$



Resistance and Resistivity

The resistance of a conductor is the obstruction posed by the conductor to the flow of current through it.

Resistance of a conductor (R) is the ratio of potential difference (V) applied across the ends of conductor to the current (I) flowing through it.

$$R = \frac{V}{I}$$

The SI unit of resistance is ohm (Ω) and its dimensional formula is $[ML^2T^{-3}A^{-2}]$.

Conductance : The reciprocal of resistance is known as conductance. It is denoted by symbol G.

$$G = \frac{1}{R}.$$

The SI unit of conductance is ohm^{-1} which is called mho and is represented by the symbol (℧). The unit mho is also called siemens (S) and its dimensional formula is $[M^{-1}L^{-2}T^3A^2]$.

The resistance of a conductor is

$$R = \frac{m}{ne^2\tau}\frac{l}{A} = \rho\frac{l}{A} \text{ where } \rho = \frac{m}{ne^2\tau}$$

where m is the mass of electron, e is charge of electron, n is the number density of electrons, τ is the relaxation time, l is the length of conductor and A is its area of cross section, ρ is the specific resistance or resistivity of the conductor.

The SI unit of resistivity is Ω m and its dimensional formula is $[ML^3T^{-3}A^{-2}]$.

Conductivity : The reciprocal of resistivity is known as conductivity or specific conductance. It is denoted by symbol σ.

$$\sigma = \frac{1}{\rho} = \frac{ne^2\tau}{m} = ne\mu \qquad \left[\text{As } \mu = \frac{v_d}{E} = \frac{e\tau}{m}\right]$$

The SI unit of conductivity is $\Omega^{-1}\,m^{-1}$ or $S\,m^{-1}$ or $mho\,m^{-1}$ and its dimensional formula is $[M^{-1}L^{-3}T^3A^2]$.

If the conductor is in the form of wire of length l and a radius r, then its resistance is

$$R = \frac{\rho l}{\pi r^2}$$

If a conductor has mass m, volume V and density d, then its resistance R is

$$R = \frac{\rho l}{A} = \frac{\rho l^2}{Al} = \frac{\rho l^2}{V} = \frac{\rho l^2 d}{m}$$

A rectangular conducting cube having dimensions $l \times b \times h$.

- When current passes through the length side, the resistance offered by cube $= \frac{\rho l}{bh}$
- When current passes through breadth side, the resistance offered by cube $= \frac{\rho b}{lh}$
- When current passes through the thickness side, the resistance offered by cube $= \frac{\rho h}{lb}$.

A cylindrical tube of length l has inner and outer radii r_1 and r_2 respectively. The resistance between its end faces is

$$R = \frac{\rho l}{\pi\left(r_2^2 - r_1^2\right)}.$$

If a wire of resistance R is cut into n equal parts, then resistance of each part = R/n.

If length of a given metallic wire of resistance R is stretched to n times, its resistance becomes n^2R but its resistivity remains unchanged.

If radius of the given metallic wire of resistance R becomes n times, its resistance becomes $(1/n^4)R$.

If the area of cross-section of the given metallic wire of resistance R becomes n times, then its resistance becomes $(1/n^2)R$.

Relationship Between J, σ and E

$$J = \sigma E$$

It is a microscopic form of Ohm's law.

Colour Code of Resistors

A colour code is used to indicate the resistance value and its percentage accuracy. Every resistor has a set of coloured rings on it. The first two coloured rings from the left end indicate the first two significant figures of the resistance in ohms. The third colour ring indicates the decimal multiplier and the last colour ring stands for the tolerance in percent. The colour code of a resistor is as shown in the table.

Colour	Number	Multiplier	Tolerance (%)
Black	0	10^0	
Brown	1	10^1	
Red	2	10^2	
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	

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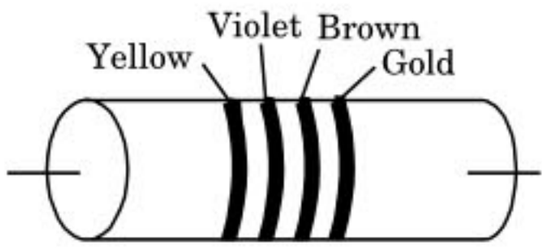
Blue	6	10^6	
Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	
Gold		10^{-1}	5
Silver		10^{-2}	10
No colour			20

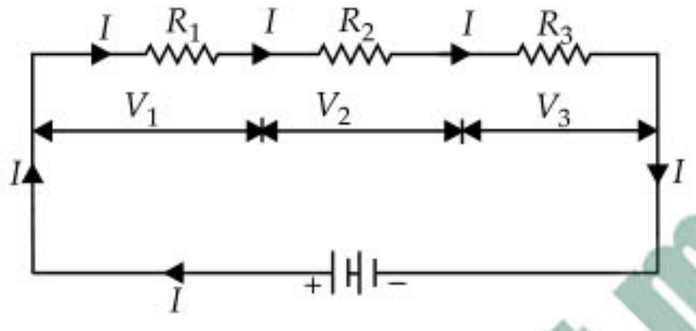
Suppose a resistor has yellow, violet, brown and gold rings as shown in the figure below. The resistance of the resistor is $(47 \times 10\ \Omega) \pm 5\%$.



Combination of Resistors

Resistors in series

The various resistors are said to be connected in series if they are connected as shown in the figure.



The current through each resistor is the same.

The equivalent resistance of the combination of resistors is

$R_s = R_1 + R_2 + R_3$

As current through each resistors is same so

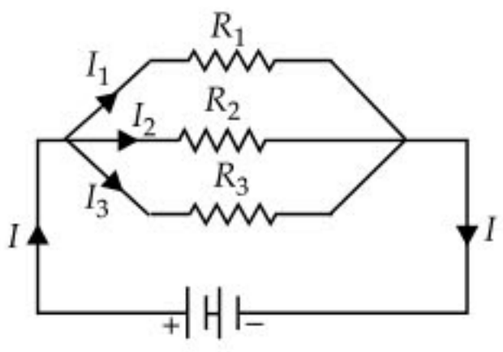
$$\frac{V_1}{R_1} = \frac{V_2}{R_2} = \frac{V_3}{R_3} \quad \text{or} \quad V_1 : V_2 : V_3 = R_1 : R_2 : R_3$$

Series combinations of resistors are used in resistance box and decorative bulbs.

If n wires each of resistance R are connected in series, the equivalent resistance is nR.

Resistors in parallel

The various resistors are said to be connected in parallel if they are connected as shown in figure below.



The potential difference is same across each resistor (say V). The equivalent resistance of the combination of resistors is

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

As $I_1 = \frac{V}{R_1}$, $I_2 = \frac{V}{R_2}$ and $I_3 = \frac{V}{R_3}$ so,

$$I_1 : I_2 : I_3 = \frac{1}{R_1} : \frac{1}{R_2} : \frac{1}{R_3}$$

All the domestic appliances in a house are connected in parallel combination.

If n wires each of resistance R are connected in parallel, the equivalent resistance is R/n.

Effect of Temperature on Resistance

The resistance of a metallic conductor increases with increase in temperature.

The resistance of a conductor at temperature T°C is given by

$$R_T = R_0(1 + \alpha T + \beta T^2)$$

where R_T is the resistance at T°C, R_0 is the resistance at 0°C and α and β are the characteristics constants of the material of the conductor. If the temperature T°C is not sufficiently large, β is negligible, the above relation can be written as

$$R_T = R_0(1 + \alpha T)$$

where α is the temperature coefficient of resistance.

Its unit is K^{-1} or $°C^{-1}$. For metals, α is positive, therefore, resistance of a metal increases with rise in temperature. For insulators and semiconductors, α is negative therefore, their resistance decreases with rise in temperature. For alloys like manganin, eureka and constantan, the value of α is very small as compared to that for metals. Due to high resistivity and low temperature coefficient of resistance, these alloys are used in making standard resistance coils.

Electrochemical Cell

It is a device which, by converting chemical energy into electrical energy, maintains the flow of charge in a circuit.

A cell is a source of constant emf but not a constant current.

Electromotive force (emf) of a cell

It is defined as the potential difference between the two terminals of a cell in an open circuit *i.e.*, when no current flows through the cell. It is denoted by symbol ε.

The SI unit of emf is joule/coulomb or volt and its dimensional formula is $[ML^2T^{-3}A^{-1}]$.

The emf of a cell depends upon the nature of electrodes, nature and the concentration of electrolyte used in the cell and its temperature.

Note : The emf is not a force.

Terminal potential difference of a cell

It is defined as the potential difference between two terminals of a cell in a closed circuit *i.e.* when current is flowing through the cell.

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It is generally denoted by symbol V and is measured in volt.

Internal resistance of a cell

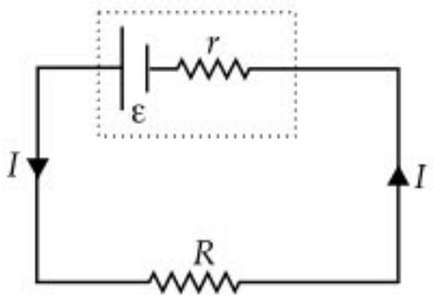
It is defined as the resistance offered by the electrolyte and electrodes of a cell when the current flows through it.

Internal resistance of a cell depends upon the following factors:

- Distance between the electrodes
- The nature of the electrolyte
- The nature of electrodes
- Area of the electrodes, immersed in the electrolyte

Relationship between ε, V and r

When a cell of emf ε and internal resistance r is connected to an external resistance R as shown in the figure.



Current in the circuit, $I = \frac{\varepsilon}{R+r}$

Terminal potential difference, $V = IR = \frac{\varepsilon R}{(R+r)}$

Internal resistance of a cell, $r = \left(\frac{\varepsilon - V}{V}\right)R = \left(\frac{\varepsilon}{V} - 1\right)R$

During discharging of a cell, terminal potential difference = emf of a cell – voltage drop across the internal resistance of a cell *i.e.* terminal potential difference across it is lesser than emf of the cell. The direction of current inside the cell is from negative terminal to positive terminal.

During charging of a cell, terminal potential difference = emf of a cell + voltage drop across internal resistance of a cell *i.e.* terminal potential difference becomes greater than the emf of the cell. The direction of current inside the cell is from positive terminal to negative terminal.

When the cell is short circuited, *i.e.*, $R = 0$, the maximum current is drawn from a cell whose value is given by

$$I_{max} = \frac{\varepsilon}{r}$$

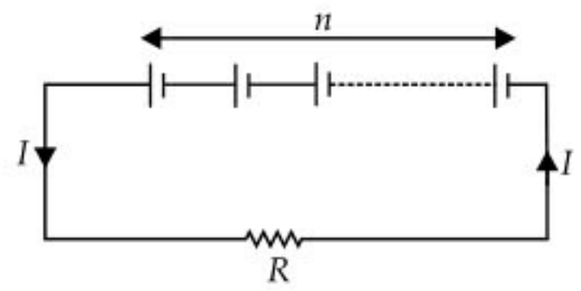
Grouping of Cells

Cells can be grouped in the following three ways:

- Series grouping
- Parallel grouping
- Mixed grouping

Series grouping

If n identical cells each of emf ε and internal resistance r are connected to the external resistor of resistance R as shown in the figure, they are said to be connected in series grouping.



Equivalent emf of the cells is $\varepsilon_{eq} = n\varepsilon$

Equivalent internal resistance of the cells is $req = nr$

Current in the circuit, $I = \frac{n\varepsilon}{R+nr}$

Special cases :

- If $R << nr$, then $I = \frac{n\varepsilon}{nr} = \frac{\varepsilon}{r}$
- If $R >> nr$, then $I = \frac{n\varepsilon}{R}$

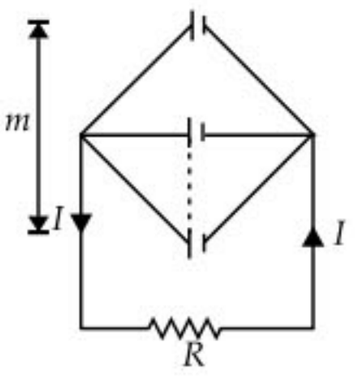
Note :

When one cell is wrongly connected in series of n identical cells, each of emf ε, it will reduce the total emf by 2ε *i.e.* effective emf = $n\varepsilon - 2\varepsilon$.

When n cells each of internal resistance r are wrongly connected in series, the total internal resistance of cells = nr *i.e.* there is no effect on the total internal resistance of the cells.

Parallel grouping

If m identical cells each of emf ε and internal resistance r are connected to the external resistor of resistance R as shown in figure, they are said to be connected in parallel grouping.



Equivalent emf of the cells is $\varepsilon_{eq} = \varepsilon$

Equivalent internal resistance of the cells is $r_{eq} = \frac{r}{m}$

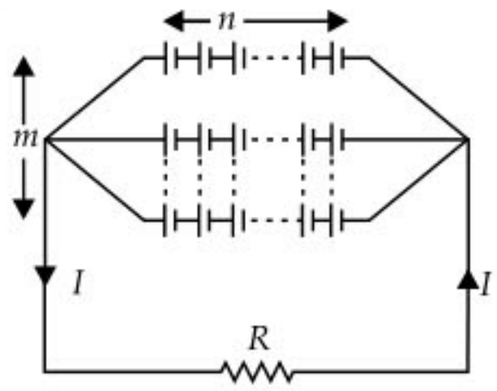
Current in the circuit, $I = \frac{\varepsilon}{R + \left(\frac{r}{m}\right)}$

Special cases :

- If $\frac{r}{m} << R$, then $I = \frac{\varepsilon}{R}$
- If $\frac{r}{m} >> R$, then $I = m\frac{\varepsilon}{r}$

Mixed grouping

If the cells are connected as shown in figures they are said to be connected in mixed grouping. Let there be n cells in series in one row and m such rows of cells in parallel. Suppose all the cells are identical. Let each cell be of emf ε and internal resistance r.



Equivalent emf of the cells is εeq = $n\varepsilon$

Equivalent internal resistance of the cells is

$$r_{eq} = \frac{nr}{m}$$

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Current in the circuit, $I = \dfrac{n\varepsilon}{R + \left(\dfrac{nr}{m}\right)}$

In case of mixed grouping of cells, current in the circuit will be maximum, when

$$R = \frac{nr}{m}$$

i.e. external resistance = total internal resistance of all cells

Kirchhoff's Laws

Kirchhoff in 1942 put forward the following two laws to solve the complicated circuits. These two laws are stated as follows :

Kirchhoff's first law or Kirchhoff's junction law or Kirchhoff's current law

It states that at any junction, the sum of the currents entering the junction is equal to the sum of currents leaving the junction.

Kirchhoff's first law is based on conservation of charge. The outgoing currents add up and are equal to incoming currents at a junction. Bending or reorienting the wire does not change the validity of Kirchhoff's junction law.

According to sign convention, the current flowing towards a junction is taken as positive and the current flowing away from the junction is taken as negative.

Kirchhoff's second law or Kirchhoff's loop law or Kirchhoff's voltage law

It states that the algebraic sum of changes in potential around any closed loop involving resistors and cells in the loop is zero.

Kirchhoff's second law is based on the law of conservation of energy.

According to sign convention while traversing a closed loop (in clockwise or anti-clockwise direction), if negative pole of the cell is encountered first then its emf is positive, otherwise negative. The product of resistance and current in an arm of the circuit is taken positive if the direction of current in that arm is in the same sense as one moves in a closed loop and is taken negative if the direction of current in that arm is opposite to the sense as one moves in the closed loop.

Some interesting conclusions using Kirchhoff's laws

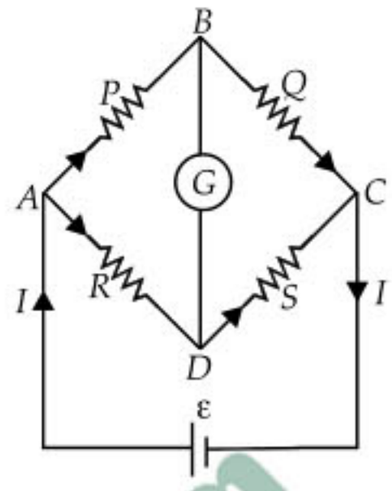
If 12 wires each of resistance $R\ \Omega$, are connected to form a skeleton cube, then the total resistance between two diagonally opposite corners of the cube = $5R/6\ \Omega$,

If 12 wires each of resistance $R\ \Omega$ are connected to form a skeleton cube, then the total resistance between the corners of the same edge of cube = $7R/12\ \Omega$.

If 11 wires each of resistance $R\ \Omega$, are connected to form a skeleton cube, then the total resistance from one end of vacant edge to the other end is = $7R/5\ \Omega$.

Wheatstone's Bridge

It is an arrangement of four resistances P, Q, R and S connected as shown in the figure.



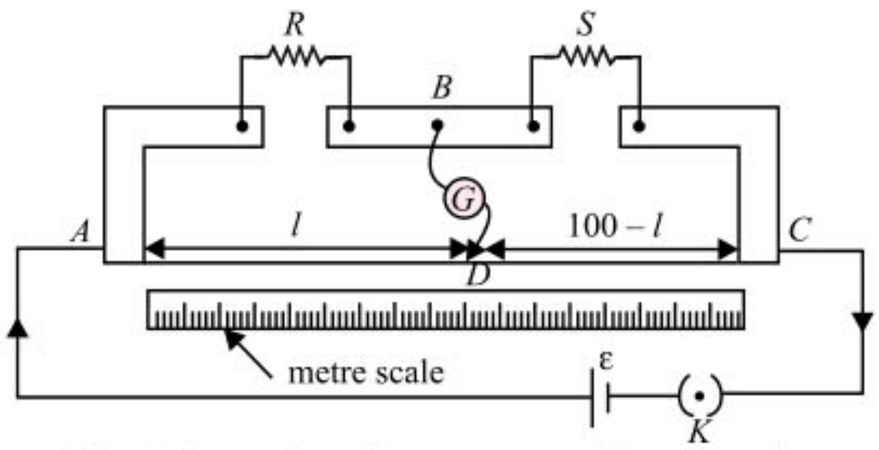
Their values are so adjusted that the galvanometer G shows no deflection. The bridge is then said to be balanced. When this happens, the points B and D are at the same potential and no current flows through galvanometer and it can be shown that

$$\frac{P}{Q} = \frac{R}{S}$$

This is called the balancing condition. If any three resistances are known, the fourth can be found.

Metre Bridge or Slide Metre Bridge

It is based on the principle of Wheatstone's bridge.



Wire AC is 1 m long. R is a resistance to be measured and S is a standard resistance of known value.

The unknown resistance, $R = \dfrac{Sl}{100 - l}$

where l is the balancing length of metre bridge.

Potentiometer

Principle of potentiometer

It is based on the fact that the fall of potential across any portion of the wire is directly proportional to the length of that portion provided the wire is of uniform area of cross-section and a constant current is flowing through it.

i.e., $V \propto l$ (If I and A are constants)

or $V = Kl$

where K is known as potential gradient *i.e.*, fall of potential per unit length of the given wire.

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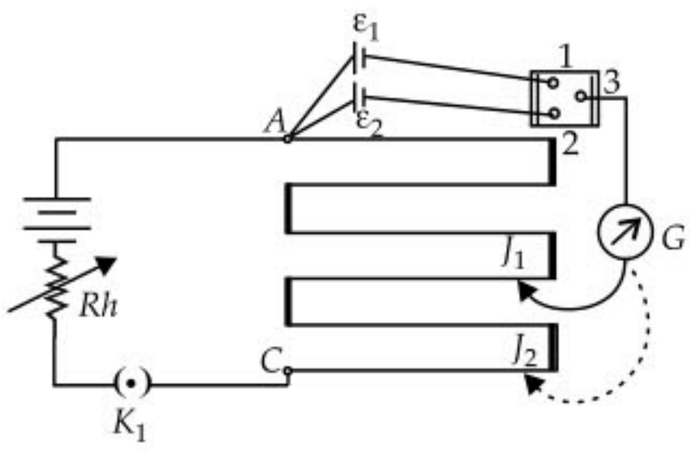
Comparison of emfs of two cells by using potentiometer

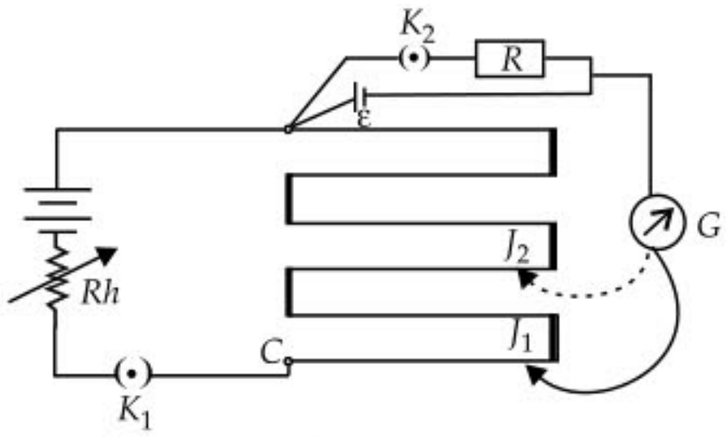


G is a galvanometer and *Rh* is rheostat, 1, 2, 3, are terminals of a two way key

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2}$$

where l_1, l_2 are the balancing lengths of potentiometer wire for the emfs ε_1 and ε_2 of two cells respectively.

Determination of internal resistance of a cell by potentiometer



$$r = \left(\frac{l_1 - l_2}{l_2}\right)R$$

where l_1 = balancing length of potentiometer wire corresponding to emf of the cell, l_2 = balancing length of potentiometer wire corresponding to terminal potential difference of the cell when a resistance R is connected in series with the cell whose internal resistance is to be determined.

Electric Power

It is defined as the rate at which work is done by the source of emf in maintaining the current in the electric circuit.

$$\text{Electric power, } P = \frac{\text{Electric work done}}{\text{Time taken}}$$

$$P = VI = I^2R = \frac{V^2}{R}.$$

The SI unit of power is watt (W).
The bigger unit of power is kilowatt (kW).
1 kilowatt = 1000 watt.
The commercial unit of power is horse power (hp)
1 hp = 746 watt.

Electric Energy

It is defined as the total electric workdone or energy supplied by the source of emf in maintaining the current in an electric circuit for a given time.
Electric energy = electric power × time

$$= Pt = VIt = I^2Rt = \frac{V^2}{R}t$$

The SI unit of electrical energy is joule (J).
The commercial unit of electric energy is kilowatt-hour (kWh), or Board Trade Unit (BTU).
1 kWh = 1000 Wh = 3.6×10^6 J
Number of units of electricity consumed

$$= \text{No. of kWh} = \frac{\text{watt} \times \text{hour}}{1000}$$

Maximum Power Transfer Theorem

It states that the power output across load due to a cell or battery is maximum if the load resistance is equal to the effective internal resistance of cell or battery.

Fuse Wire

It is generally made up of tin-lead alloy.
It should have low resistivity and low melting point.
It is used in the series of the electrical installations to protect them from strong currents.

Note :

If one heater boils a certain mass of water in time t_1 and another heater boils the same mass of water in time t_2, then connecting both the heaters in series, the same water will boil in time $(t_1 + t_2)$; when connecting both the heaters in parallel the same water will boil in time $t = \frac{t_1 \times t_2}{t_1 + t_2}$.

If P_1, P_2, P_3 .... are the powers of electric appliances in series with source of rated voltage V, the effective power consumed is

$$\frac{1}{P_S} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3} + ...$$

If P_1, P_2, P_3.... are the powers of electric appliances in parallel with a source of rated voltage V, the effective power consumed is

$$P_P = P_1 + P_2 + P_3 + ...$$

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EXAM DRILL

1. The voltage of a cloud is 4×10^6 volts with respect to ground. In a lightening strike lasting 100 m s^{-1}, a charge of 4 coulombs is delivered to the ground. The power of the lightening strike is
(a) 160 MW (b) 80 MW
(c) 20 MW (d) 500 MW

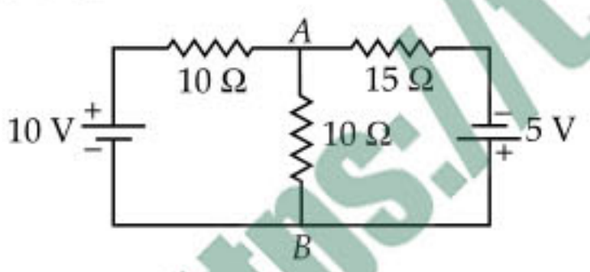
2. Two resistors 400 Ω and 800 Ω are connected in series with a 6 V battery. The potential difference measured by voltmeter of 10 kΩ across 400 Ω resistor is
(a) 2V (b) 1.95 V (c) 3.8 V (d) 4 V

3. An electric bulb is marked 100 W, 230 V. If the supply voltage drops to 115 V, what is the heat and light energy produced by the bulb in 20 min?
(a) 20,000 J (b) 25,000 J
(c) 30,000 J (d) 35,000 J

4. Five equal resistors when connected in series dissipated 5 W power. If they are connected in parallel, the power dissipated will be
(a) 25 W (b) 50 W (c) 100 W (d) 125 W

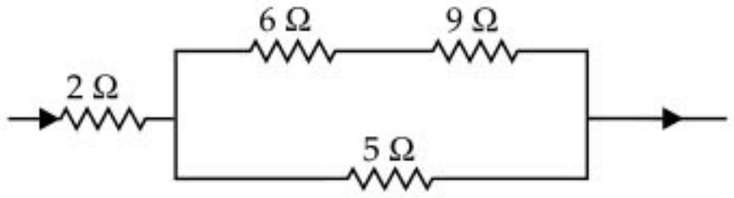
5. The dimensions of a block are 1 cm × 1 cm × 100 cm. If the specific resistance of its material is 3×10^{-7} ohm m, then the resistance between the opposite rectangular faces is
(a) 3×10^{-9} ohm (b) 3×10^{-7} ohm
(c) 3×10^{-5} ohm (d) 3×10^{-3} ohm

6. A circuit is as shown in the figure. Then, the current from A to B is



(a) + 500 mA (b) + 250 mA
(c) – 250 mA (d) – 500 mA

7. In the circuit shown in figure, if the resistance 5 Ω develops a heat 42 J per second, the heat developed in 2 Ω must be about (in J s^{-1})



(a) 25 (b) 20 (c) 30 (d) 35

8. The temperature coefficient of a resistance wire is 0.00125 per degree. The resistance at 300 K is 1 ohm. At what temperature its resistance will be 2 ohm?
(a) 1154 K (b) 1127 K
(c) 600 K (d) 1400 K

9. A wire of resistance R is stretched till its length is double of the original wire. Then, the resistance of the stretched wire is
(a) $2R$ (b) $4R$ (c) $8R$ (d) $16R$

10. The resistivity of a potentiometer wire is 40×10^{-8} Ω m and its area of cross-section is 8×10^{-6} m^2. If 0.2 A current is flowing through the wire, the potential gradient will be
(a) 10^{-2} V m^{-1} (b) 10^{-1} V m^{-1}
(c) 3.2×10^{-2} V m^{-1} (d) 1 V m^{-1}

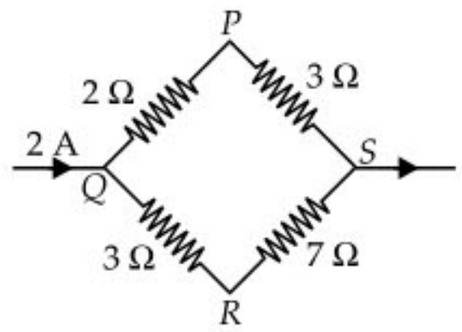
11. A bulb of 220 V and 300 W is connected across 110 V circuit. The percentage reduction in power is
(a) 100% (b) 25% (c) 70% (d) 75%

12. If a wire of resistance 20 Ω is covered with ice (at 0°C) and a voltage of 210 V is applied across the wire, then the rate of melting of ice is
(a) 0.85 g s^{-1} (b) 1.92 g s^{-1}
(c) 6.59 g s^{-1} (d) none of these

13. Masses of the three wires of same material are in the ratio of 1 : 2 : 3 and their lengths in the ratio of 3 : 2 : 1. Electrical resistance of these wires will be in the ratio of
(a) 1 : 1 : 1 (b) 1 : 2 : 3
(c) 9 : 4 : 1 (d) 27 : 6 : 1

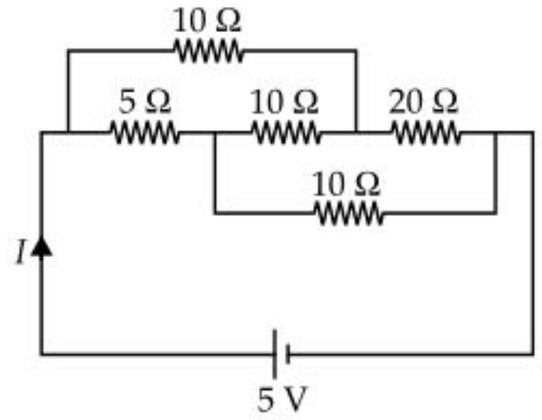
14. A resistance of 2 Ω is to be made from a copper wire (specific resistance 1.7×10^{-8} Ω m) using a wire of length 50 cm. The radius of the wire is
(a) 0.0116 mm (b) 0.0367 mm
(c) 0.116 mm (d) 0.367 mm

15. A current of 2 A flows in the system of conductors as shown in the figure. The potential difference $V_P - V_R$ will be



(a) –2 V (b) –1 V (c) + 1 V (d) + 2 V

16. The current I drawn from the 5 V source will be



(a) 0.33 A (b) 0.5 A (c) 0.67 A (d) 0.17 A

17. A cell in secondary circuit gives null deflection for 2.5 m length of potentiometer having 10 m length of wire. If the length of the potentiometer wire is increased by 1 m without changing the cell in the primary, the position of the null point now is
(a) 3.5 m (b) 3 m (c) 2.75 m (d) 2.0 m

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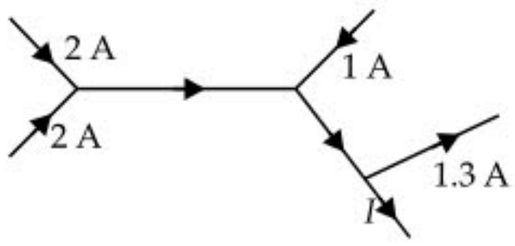
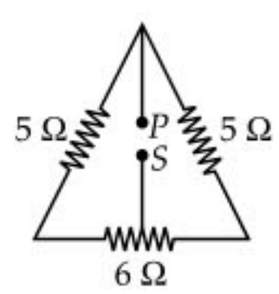
18. In the figure a part of electric circuit has been shown. The value of current I is



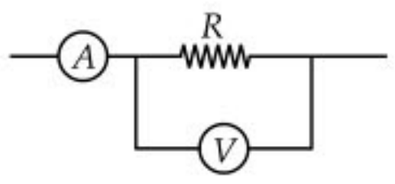
(a) 1.7 A (b) 3.7 A (c) 1.3 A (d) 1 A

19. Three resistances 5 Ω, 5 Ω and 6 Ω are connected as shown in figure. If the point S divides the resistance 6 Ω into two equal halves, the resistance between points P and S is



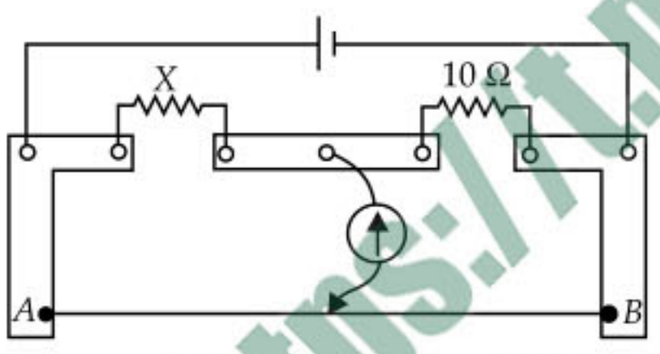
(a) 11 Ω (b) 8 Ω
(c) 6 Ω (d) 4 Ω

20. In the circuit shown in figure, the ammeter shows 5 A current, voltmeter shows 250 V and the internal resistance of the voltmeter is 2500 Ω, then the value of R is



(a) 150 Ω
(b) 0.51 Ω
(c) 510 Ω
(d) 51 Ω

21. A meter bridge is set-up as shown, to determine an unknown resistance X using a standard 10 Ω resistor. The galvanometer shows null point when tapping key is at 52 cm mark. The end corrections are 1 cm and 2 cm respectively for the ends A and B. The determined value of X is



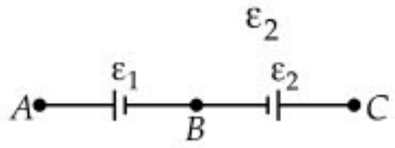
(a) 10.2 Ω (b) 10.6 Ω (c) 10.8 Ω (d) 11.1 Ω

22. Two wires of equal diameters of resistivities ρ_1 and ρ_2 and lengths l_1 and l_2 respectively are joined in series. The equivalent resistivity of the combination is

(a) $\dfrac{\rho_1 l_1 + \rho_2 l_2}{l_1 + l_2}$ (b) $\dfrac{\rho_1 l_2 - \rho_2 l_1}{l_1 - l_2}$

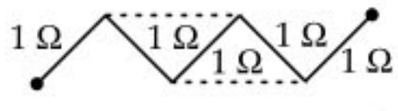
(c) $\dfrac{\rho_1 l_2 + \rho_2 l_1}{l_1 + l_2}$ (d) $\dfrac{\rho_1 l_1 - \rho_2 l_2}{l_1 - l_2}$

23. Two cells of emfs ε_1 and $\varepsilon_2 (\varepsilon_1 > \varepsilon_2)$ are connected as shown in figure. When a potentiometer is connected between A and B, the balancing length of the potentiometer wire is 300 cm. On connecting the same potentiometer between A and C, the balancing length is 100 cm. The ratio $\dfrac{\varepsilon_1}{\varepsilon_2}$ is



(a) 3 : 1 (b) 1 : 3 (c) 2 : 3 (d) 3 : 2

24. A circuit consists of five identical identical conductors as shown In the figure. The two similar conductors are added as indicated by the dotted lines. The ratio of resistances before and after addition will be



(a) $\left(\dfrac{7}{5}\right)$ (b) $\left(\dfrac{3}{5}\right)$
(c) $\left(\dfrac{5}{3}\right)$ (d) $\left(\dfrac{6}{5}\right)$

25. A battery charger supplies a current of 10 A to charge a storage battery which has an open circuit voltage of 5.6 V. If the voltmeter connected across the charger reads 6.8 V, what is the internal resistance of the battery?

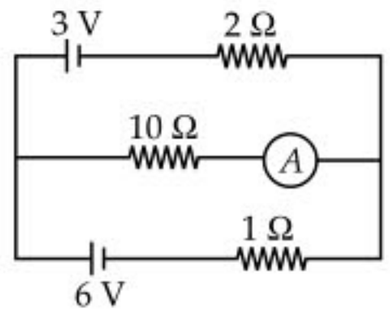
(a) 0.12 Ω (b) 0.16 Ω (c) 0.18 Ω (d) 0.2 Ω

26. A battery of emf ε and internal resistance r is connected to a resistor of resistance R_1 and QJ of heat is produced in a certain time t. When the same battery is connected to another resistor of resistance R_2, the same quantity of heat is produced in the same time t. Then, the value of r is

(a) $\dfrac{R_2^2}{R_1}$ (b) $\dfrac{1}{2}(R_1 + R_2)$
(c) $\sqrt{R_1 R_2}$ (d) $\dfrac{R_1^2}{R_2}$

27. In the circuit as shown in figure, the current in ammeter is

(a) $\dfrac{42}{32}$ A
(b) $\dfrac{27}{32}$ A
(c) $\dfrac{15}{32}$ A
(d) $\dfrac{32}{15}$ A



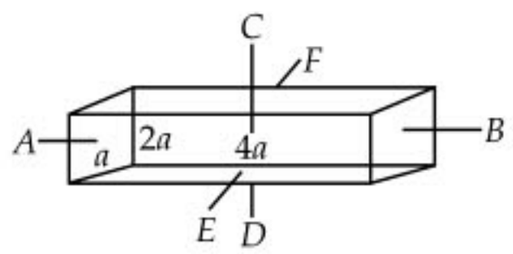
28. If 400 Ω of resistance is made by adding four 100 Ω resistance of tolerance 5%, then the tolerance of the combination is

(a) 20% (b) 5% (c) 10% (d) 15%

29. A flash light lamp is marked 3.5 V and 0.28 A. The filament temperature is 425°C. The filament resistance at 0°C is 4 Ω. Then, the temperature coefficient of resistance of the material of the filament is

(a) $8.5 \times 10^{-3} °C^{-1}$ (b) $3.5 \times 10^{-3} °C^{-1}$
(c) $0.5 \times 10^{-3} °C^{-1}$ (d) $5 \times 10^{-3} °C^{-1}$

30. A conductor with rectangular cross-section has dimensions $(a \times 2a \times 4a)$ as shown in figure. Resistance across AB is R_1, across CD is R_2 and across EF is R_3. Then



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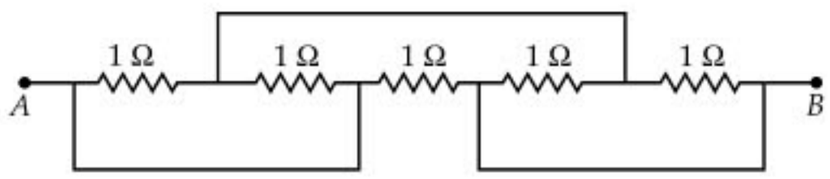
(a) $R_1 = R_2 = R_3$ (b) $R_1 > R_2 > R_3$
(c) $R_2 > R_3 > R_1$ (d) $R_1 > R_3 > R_2$

31. Resistors each of value 1 Ω are arranged as shown in the figure. The equivalent resistance between points A and B is



(a) $\frac{1}{2}\Omega$ (b) $\frac{1}{5}\Omega$ (c) $\frac{5}{4}\Omega$ (d) $\frac{4}{5}\Omega$

32. Two cells of emf 2 V and 1 V and of internal resistance 1 Ω and 2 Ω respectively have their positive terminals connected by a wire of 10 Ω resistance and their negative terminals by a wire of 4 Ω resistance. Another coil of 10 Ω is connected between the middle of these wires. The potential difference across the 10 Ω coil is
(a) 1.07 V (b) 2.03 V
(c) 3.45 V (d) 4.25 V

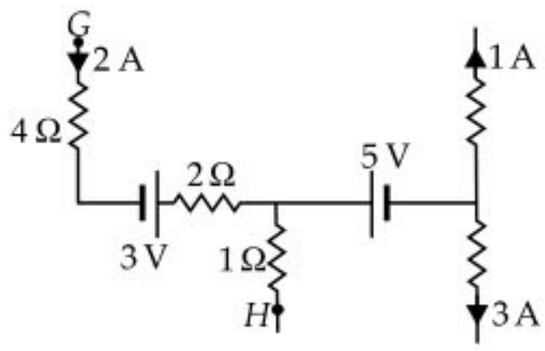
33. Ends of two wires A and B having resistivity $\rho_A = 3 \times 10^{-5}$ Ω m and $\rho_B = 6 \times 10^{-5}$ Ω m of same cross section area are joined together to form a single wire. If the resistance of the joined wire does not change with temperature, then find the ratio of their lengths, given that temperature coefficient of resistivity of wire A and B is $\alpha_A = 4 \times 10^{-5}°C^{-1}$ and $\alpha_B = -6 \times 10^{-6}°C^{-1}$. Assume that mechanical dimensions do not change with temperature.
(a) $\frac{3}{7}$ (b) $\frac{10}{3}$ (c) $\frac{3}{10}$ (d) $\frac{1}{2}$

34. Three resistances of 4 Ω, 6 Ω and 12 Ω are connected in parallel and the combination is connected in series with 4 V battery with internal resistance of 2 Ω. The battery current is
(a) 1 A (b) 10 A
(c) 2 A (d) 0.5 A

35. **Statement-1 :** In order to have maximum current, a series combinations of cells is used where their internal resistance is much smaller than the external resistance.
Statement-2 : Current flowing through the circuit is inversely proportional to total resistance.
(a) Statement-1 is true, Statement-2 is false.
(b) Statement-1 is true, Statement-2 is true; Statement-2 is a correct explanation for Statement-1.
(c) Statement-1 is true, Statement-2 is true; Statement-2 is not a correct explanation for Statement-1.
(d) Statement-1 is false, Statement-2 is true.

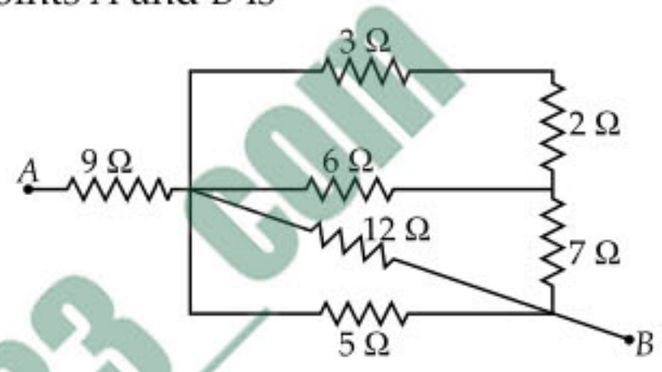
36. Three unequal resistors in parallel are equivalent to a resistance 1 Ω. If two of them are in the ratio 1 : 2 and if no resistance value is fractional, the largest of the three resistances in Ω is
(a) 4 (b) 6
(c) 5 (d) 12

37. In the part of a circuit shown in figure, the potential difference between points G and H ($V_G - V_H$) will be



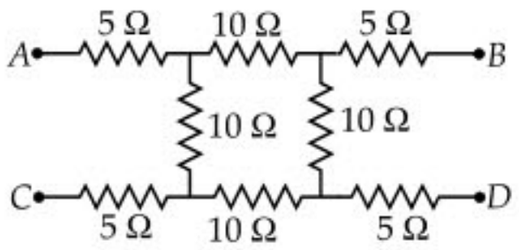
(a) 0 V (b) 12 V (c) 7 V (d) 3 V

38. In the given circuit the equivalent resistance between the points A and B is



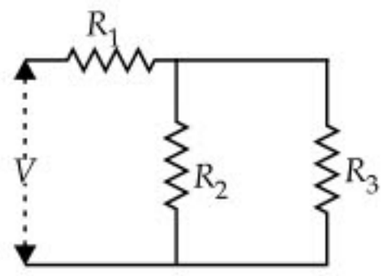
(a) 9 Ω (b) 11.6 Ω
(c) 14.5 Ω (d) 21.2 Ω

39. The equivalent resistance between the terminals A and D in the following circuit is

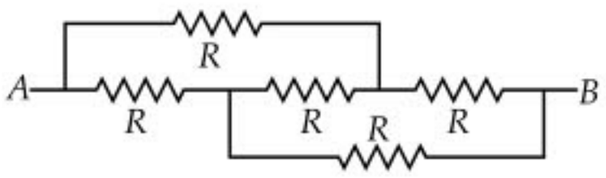


(a) 10 Ω (b) 20 Ω
(c) 5 Ω (d) 30 Ω

40. For ensuring dissipation of same energy in all three resistors (R_1, R_2, R_3) connected as shown in figure, their values must be related as
(a) $R_1 = R_2 = R_3$
(b) $R_2 = R_3$ and $R_1 = 4R_2$
(c) $R_2 = R_3$ and $R_1 = \frac{R_2}{4}$
(d) $R_1 = R_2 + R_3$

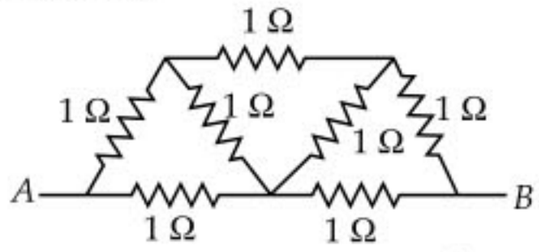


41. The equivalent resistance between A and B is



(a) $4R$ (b) $2R$
(c) R (d) $3R$

42. Seven resistors, each of 1 Ω resistance are connected as shown in figure. What is the effective resistance between A and B?



(a) $\frac{4}{7}\Omega$ (b) 7 Ω (c) $\frac{8}{7}\Omega$ (d) $\frac{3}{2}\Omega$

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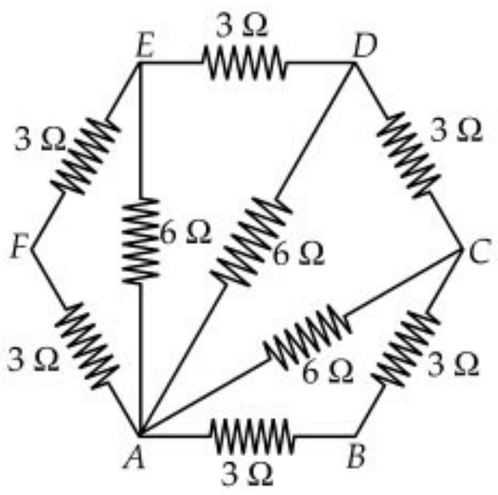
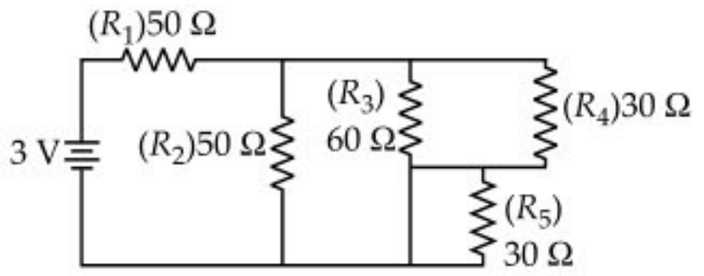
43. Figure below shows a network of resistances. The effective resistance between points A and B of network is



(a) $\left(\frac{3}{2}\right)\Omega$ (b) $6\ \Omega$

(c) $3\ \Omega$ (d) $2\ \Omega$

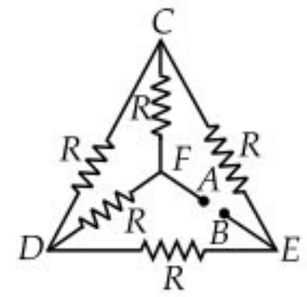
44. In the given circuit voltage across R_4 is



(a) 0.4 V (b) 0.6 V

(c) 0.8 V (d) 1.0 V

45. Five equal resistances each of resistance R are connected as shown in the figure. A battery of V volt is connected between A and B. The current flowing in $AFCEB$ will be



(a) $\frac{3V}{R}$ (b) $\frac{V}{R}$ (c) $\frac{V}{2R}$ (d) $\frac{2V}{R}$

DAY 17 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ

Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____

(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (a) : Work done = charge × potential difference

$W = 4 \times (4 \times 10^6 - 0) = 16 \times 10^6$ J

Power of the lightening strike,

$$P = \frac{W}{t} = \frac{16\times10^6}{100\times10^{-3}} = 160 \text{ MW}$$

2. (b) : Here, the resistances of 400 Ω and 10000 Ω are in parallel, their effective resistance R_P will be

$$R_P = \frac{400\times10000}{400+10000} = \frac{5000}{13}\Omega$$

Total resistance of the circuit,

$$= \frac{5000}{13} + 800 = \frac{15400}{13}\Omega$$

Current in the circuit

$$I = \frac{6}{15400/13} = \frac{39}{7700}\text{A}$$

Potential difference across voltmeter

$= IR_P$

$$= \frac{39}{7700}\times\frac{5000}{13} = 1.95 \text{ V}$$

3. (c) : Here, $P = 100$ W; $V = 230$ V

Let R be resistance of the filament of the bulb.

Now, electric power, $P = VI = \frac{V^2}{R}$

Therefore, $R = \frac{V^2}{P} = \frac{(230)^2}{100} = 529\ \Omega$

when the voltage drops to 115 V, heat and light energy produced by the bulb in 20 min is given by

$$W = VIt = \frac{V^2}{R}t = \frac{(115)^2}{529}\times20\times60 = 30{,}000 \text{ J}$$

4. (d) : In series, total resistance of 5 resistors = $5R$

Power dissipated $= \frac{V^2}{5R} = 5$

or $= \frac{V^2}{R} = 25$

In parallel, total power = $5\left(\frac{V^2}{R}\right) = 5\times25 = 125$ W

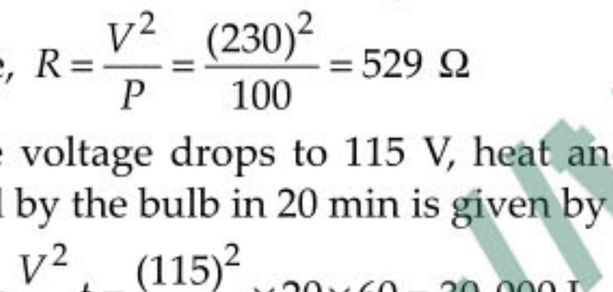
5. (b) : $R = (\rho l/A)$

$\rho = 3\times10^{-7}$ ohm m, $l = 1$ cm $= 10^{-2}$ m

And $A = 1\times100 \text{ cm}^2 = 10^{-2} \text{ m}^2$

$$\therefore\quad R = 3\times10^{-7}\times\frac{10^{-2}}{10^{-2}} = 3\times10^{-7} \text{ ohm}$$

6. (b) :



Applying Kirchhoff second law for a closed loop *CABDC*, we get

$$-10I_1 - (I_1 - I_2)10 + 10 = 0$$

$$-20I_1 + 10I_2 = -10$$

$$2I_1 - I_2 = 1 \qquad \text{...(i)}$$

Again, applying Kirchhoff second law for a closed loop *ABFEA*, we get

$$-(I_1 - I_2)10 - 5 + 15I_2 = 0$$

$$-10I_1 + 25I_2 = 5$$

$$2I_1 - 5I_2 = -1 \qquad \text{...(ii)}$$

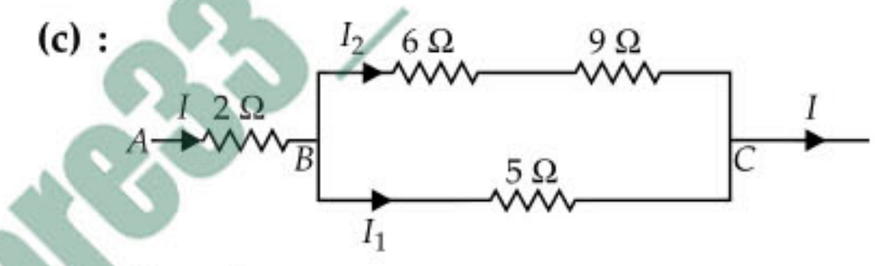
Solving (i) and (ii), we get

$$I_1 = \frac{3}{4}\text{A},\ I_2 = -\frac{1}{2}\text{A}$$

The current flows from A to B is

$$= I_1 - I_2 = \frac{3}{4}\text{A} - \frac{1}{2}\text{A} = \frac{1}{4}\text{A} = 0.25 \text{ A} = 250 \text{ mA}$$

7. (c) :



$$I_1 = \frac{I\times15}{5+6+9} = \frac{3}{4}I \qquad \text{...(i)}$$

and $I_2 = \frac{I\times5}{5+6+9} = \frac{1}{4}I$ ...(ii)

Heat developed in 5 Ω per second

$$= I_1^2\times5 = 42 \text{ J s}^{-1} \qquad \text{(Given)}$$

$$\therefore\quad I_1^2 = \frac{42}{5} \qquad \text{...(iii)}$$

From (i) and (iii), we get

$$I^2 = \frac{16\times42}{9\times5}$$

Heat developed in 2 Ω per second = $I^2 \times 2$

$$= \frac{16\times42\times2}{9\times5} \approx 30 \text{ J s}^{-1}$$

8. (b) : Temperature, $t = 300$ K $= 27°$C

$R_{27} = 1 = R_0(1 + 0.00125\times27)$

$R_t = 2 = R_0(1 + 0.00125\times t)$

$$\therefore\quad \frac{2}{1} = \frac{1+0.00125\times t}{1+0.00125\times27}$$

On solving, $t = 854°$C $= 854 + 273 = 1127$ K.

9. (b) : Resistance R of a wire of length l and radius r with specific resistance K for its material is given by

$$R = \rho l/\pi r^2 \qquad \text{...(i)}$$

As the wire is stretched, there is no change in its mass M.

But $M = \pi r^2 ld$,

or $\pi r^2 = M/ld$

$$\text{Hence, } R = \frac{\rho l}{M/ld} = \left(\frac{\rho d}{M}\right)l^2 \qquad \text{...(ii)}$$

Let the resistance of the stretched wire be R'; then

$$R' = \left(\frac{\rho d}{M}\right)(2l)^2 = 4R$$

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10. (a) : The resistance of 1 m length wire will be

$$R = \frac{(40\times10^{-8})}{(8\times10^{-6})} = 5\times10^{-2}\ \Omega$$

Potential gradient,

$$\frac{\Delta V}{\Delta x} = \frac{R.I}{l}$$

$$\frac{\Delta V}{\Delta x} = (5\times10^{-2})\times0.2 = 10^{-2}\ \text{V m}^{-1}$$

11. (d) : $P = 300$ W, $V = 220$ V

$$R = \frac{V^2}{P} = \frac{220\times220}{300} = \frac{484}{3}\ \Omega$$

If this bulb is connected across 110 V, then the power delivered is

$$P' = \frac{V^2}{R} = \frac{(110)^2}{484/3} = \frac{110\times110\times3}{484} = 75\ \text{W}$$

$\therefore$ Percentage reduction in power

$$= \frac{300-75}{300}\times100\% = 75\%$$

12. (c) : $\frac{dm}{dt} = \frac{(V^2/R)}{L} = \frac{(210)^2/20}{80\times4.18} = 6.59\ \text{g s}^{-1}$

13. (d) : Mass, M = volume × density = $Al \times d$

or $A = M/ld$

Resistance, $R = \rho l/A = \rho l/(M/ld)$

$$= \frac{\rho l^2 d}{M}$$

So, $R \propto l^2/M$

Thus, $R_1 : R_2 : R_3 = \frac{l_1^2}{M_1} : \frac{l_1^2}{M_2} : \frac{l_3^2}{M_3}$

$$= \frac{3^2}{1} : \frac{2^2}{2} : \frac{1^2}{3} = 27 : 6 : 1$$

14. (b) : $A = \pi r^2 = \rho l/R$ or $r = (\rho l/\pi R)^{1/2}$

or $r = \left(\frac{1.7\times10^{-8}\times0.5}{3.14\times2}\right)^{1/2}$

or $r = 0.0367$ mm

15. (b) : Resistance between Q and S,

$$R' = \frac{5\times10}{5+10} = \frac{10}{3}\Omega$$

Potential difference across Q and S,

$$V_Q - V_S = \frac{2\times10}{3} = \frac{20}{3}\text{V} \qquad ...(i)$$

Current through arm QPS, $I_1 = \frac{20}{3\times5} = \frac{4}{3}\text{A}$

$$V_Q - V_P = \frac{4}{3}\times2 = \frac{8}{3}\text{V}$$

Current through arm QRS, $I_2 = \frac{20/3}{10} = \frac{2}{3}\text{A}$

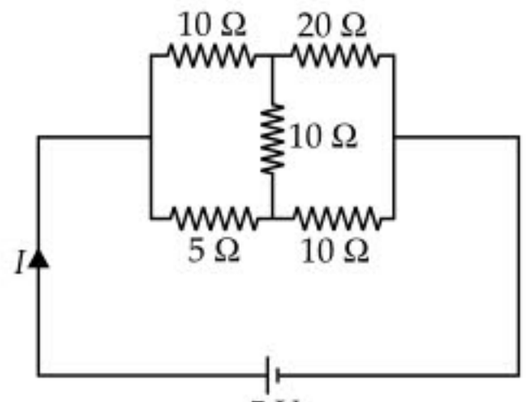
$$V_Q - V_R = \frac{2}{3}\times3 = 2\ \text{V} \qquad ...(ii)$$

From equations (i) & (ii),

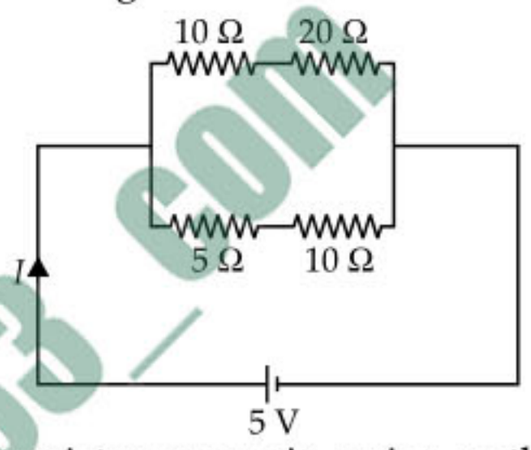
$V_P - V_R = (V_Q - V_R) - (V_Q - V_P)$

$$= 2 - \frac{8}{3} = \frac{-2}{3} \approx -1\ \text{V}.$$

16. (b) : The given circuit can be redrawn as



It is a balanced Wheatstone bridge and hence, no current flows in the middle resistor. So, equivalent circuit would be as shown in the figure.



10 Ω and 20 Ω resistances are in series, so their equivalent resistance is

$\therefore$ $R' = 10\ \Omega + 20\ \Omega = 30\ \Omega$

Similarly, 5 Ω and 10 Ω are in series, so their equivalent resistance is

$R'' = 15\ \Omega$

R' and R'' are in parallel, so the equivalent resistance of the circuit is

$$R = \frac{15\times30}{15+30} = 10\ \Omega$$

$\therefore$ $I = \frac{V}{R} = \frac{5\ \text{V}}{10\ \Omega} = 0.5\ \text{A}$

17. (c) : In first case,

Potential gradient, $k = \frac{\varepsilon_0}{l} = \frac{\varepsilon_0}{10}$

where ε_0 is the emf of the battery in the potentiometer circuit.

As per question,

$$\varepsilon = k\times2.5 = \frac{\varepsilon_0}{10}\times2.5 \qquad ...(i)$$

In second case,

Length of potentiometer wire = 10 + 1 = 11 m

Potential gradient, $k' = \frac{\varepsilon_0}{11}$

If l' is the new balancing length, then

$$\varepsilon = k'l' = \frac{\varepsilon_0}{11}\times l' \qquad ...(ii)$$

Equating (i) and (ii), we get

$\frac{\varepsilon_0}{10}\times2.5 = \frac{\varepsilon_0}{11}\times l'$ or $l' = \frac{2.5\times11}{10} = 2.75$ m

18. (b) : Using Kirchhoff first law we can find current distribution in the given part of an electric circuit as shown in the figure.

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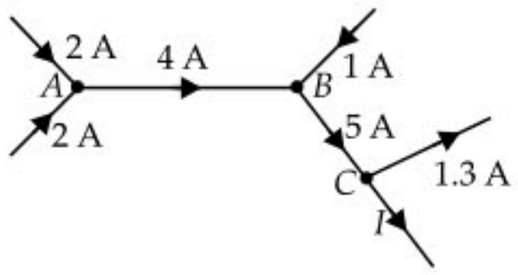
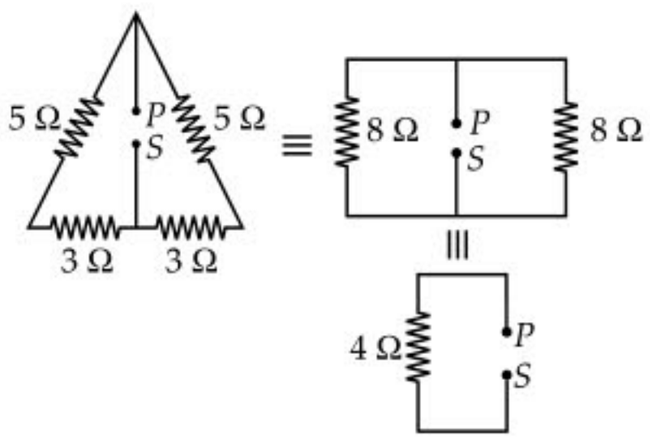


From figure, $I = 5\text{ A} - 1.3\text{ A} = 3.7\text{ A}$.

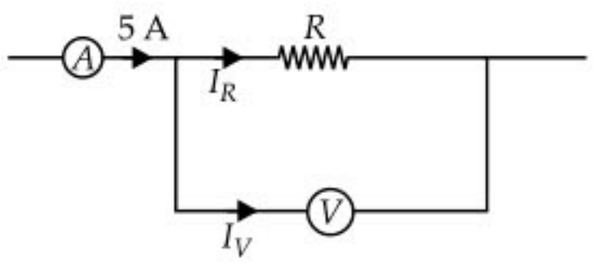
19. (d) :



20. (d) : Current flowing through the voltmeter is

$$I_V = \frac{250\text{ V}}{2500\ \Omega} = \frac{1}{10}\text{A}$$

Current flowing through the resistor R is



$$I_R = 5\text{ A} - \frac{1}{10}\text{ A} = \frac{49}{10}\text{ A}$$

Potential difference across resistance R is

$V_R = 250$ V

[$\because$ R is connected in parallel with voltmeter]

$$\therefore \quad R = \frac{V_R}{I_R} = \frac{250\text{ V}}{\frac{49}{10}\text{A}} = 51\ \Omega$$

21. (b) : Applying the condition of balanced Wheatstone bridge, we get

$$\frac{X}{10\ \Omega} = \frac{(52+1)\text{ cm}}{(100-52+2)\text{ cm}} = \frac{53}{50}$$

$$X = 10\ \Omega \times \frac{53}{50} = 10.6\ \Omega$$

22. (a) : Resistance of a wire, $R = \dfrac{4\rho l}{\pi D^2}$

where l is the length, D is the diameter and ρ is the resistivity of the material of the wire.

As the wires are connected in series, then

$$\frac{4\rho_S(l_1+l_2)}{\pi D^2} = \frac{4\rho_1 l_1}{\pi D^2} + \frac{4\rho_2 l_2}{\pi D^2}$$

[$\because$ Since the wires of same diameter]

where ρ_S is the equivalent resistivity

$$\rho_S(l_1 + l_2) = \rho_1 l_1 + \rho_2 l_2$$

or $$\rho_S = \frac{\rho_1 l_1 + \rho_2 l_2}{l_1 + l_2}$$

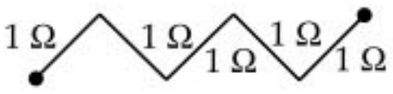
23. (d) : When potentiometer is connected between A and B, then it measures only ε_1 and when connected between A and C, then it measures $\varepsilon_1 - \varepsilon_2$.

$$\therefore \quad \frac{\varepsilon_1}{\varepsilon_1 - \varepsilon_2} = \frac{l_1}{l_2},\ \frac{\varepsilon_1 - \varepsilon_2}{\varepsilon_1} = \frac{l_2}{l_1}$$

$$\text{or} \quad 1 - \frac{\varepsilon_2}{\varepsilon_1} = \frac{100}{300} \text{ or } \frac{\varepsilon_2}{\varepsilon_1} = 1 - \frac{1}{3}$$

$$\text{or} \quad \frac{\varepsilon_2}{\varepsilon_1} = \frac{2}{3} \text{ or } \frac{\varepsilon_1}{\varepsilon_2} = \frac{3}{2}$$

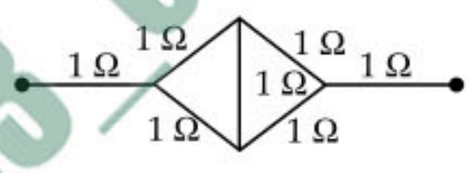
24. (c) : Before addition,



Total resistance of the circuit is

$R_1 = 5\ \Omega$

After addition the two conductors, the circuit will acquire the form as shown in figure.



It is a balanced Wheatstone bridge. Resistance of central conductor is ineffective.

$\therefore$ Total resistance of the circuit is

$$R_2 = 1\ \Omega + \frac{(2\ \Omega)(2\ \Omega)}{(2\ \Omega + 2\ \Omega)} + 1\ \Omega$$

$$= 1\ \Omega + 1\ \Omega + 1\ \Omega = 3\ \Omega$$

$$\therefore \quad \frac{R_1}{R_2} = \frac{5}{3}$$

25. (a) : Let r be internal resistance of the battery. Since the battery is charging,

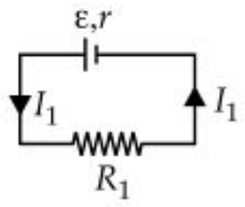
$\therefore \quad V = \varepsilon + Ir,$

Here, $I = 10$ A, $\varepsilon = 5.6$ V and $V = 6.8$ V

$$\therefore \quad 6.8 = 5.6 + 10r \text{ or } r = \frac{1.2}{10} = 0.12\ \Omega$$

26. (c) : In the first case

Current in the circuit, $I_1 = \dfrac{\varepsilon}{R_1 + r}$



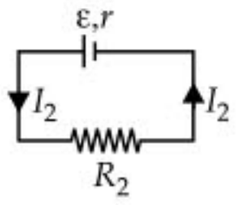
Amount of heat produced in resistor R_1 in time t is

$$Q_1 = I_1^2 R_1 t = \frac{\varepsilon^2}{(R_1 + r)^2} R_1 t \quad \text{...(i)}$$

In the second case,

Current in R_1 the circuit,

$$I_2 = \frac{\varepsilon}{r + R_2}$$



Amount of heat produced in resistor R_2 in the same time t is

$$Q_2 = I_2^2 R_2 t = \frac{\varepsilon^2}{(r + R_2)^2} R_2 t \quad \text{...(ii)}$$

As per question,

$Q_1 = Q_2 = Q$

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From (i) and (ii), we get

$$\frac{\varepsilon^2 R_1 t}{(r+R_1)^2} = \frac{\varepsilon^2 R_2 t}{(r+R_2)^2}$$

$$\frac{R_1}{(r+R_1)^2} = \frac{R_2}{(r+R_2)^2}$$

On solving, we get

$$r = \sqrt{R_1 R_2}$$

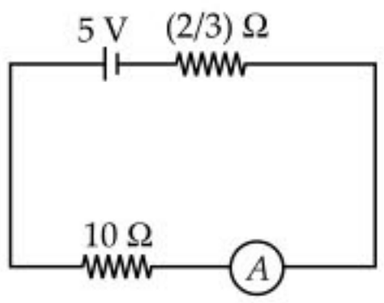
27. (c) : The equivalent emf of the two cells in parallel circuit,

$$\varepsilon_{eq} = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2} = \frac{3\times1 + 6\times2}{2+1} = 5\text{ V}$$

The effective internal resistance of two cells in parallel circuit,

$$r_{eq} = \frac{r_1 r_2}{r_1 + r_2} = \frac{2\times1}{2+1} = \frac{2}{3}\Omega$$

The equivalent circuit will be as shown in figure.



Current in ammeter, $I = \dfrac{5\text{ V}}{10\,\Omega + \frac{2}{3}\Omega} = \dfrac{15}{32}\text{A}$

28. (b) : When four resistances each of 100 Ω with tolerance 5%, are put in series, the total resistance becomes 400 Ω but the tolerance remains 5%.

29. (d) : Resistance of the lamp, $R = \dfrac{3.5\text{ V}}{0.28\text{ A}} = 12.5\,\Omega$

As $R_T = R_0(1+\alpha T)$

$\therefore \quad 12.5 = 4(1+\alpha\times425)$

$3.125 = 1+\alpha\times425$

$$\alpha = \frac{2.125}{425} = 5\times10^{-3}{}^{\circ}\text{C}^{-1}$$

30. (d) : $R = \dfrac{\rho l}{A}$

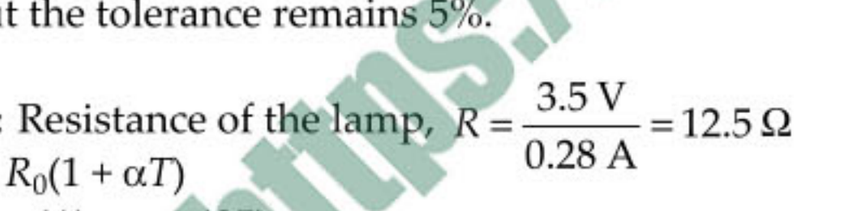
where the symbols have their usual meanings.

$\therefore \quad R_1 = \dfrac{\rho(4a)}{(2a)(a)} = \dfrac{2\rho}{a}$

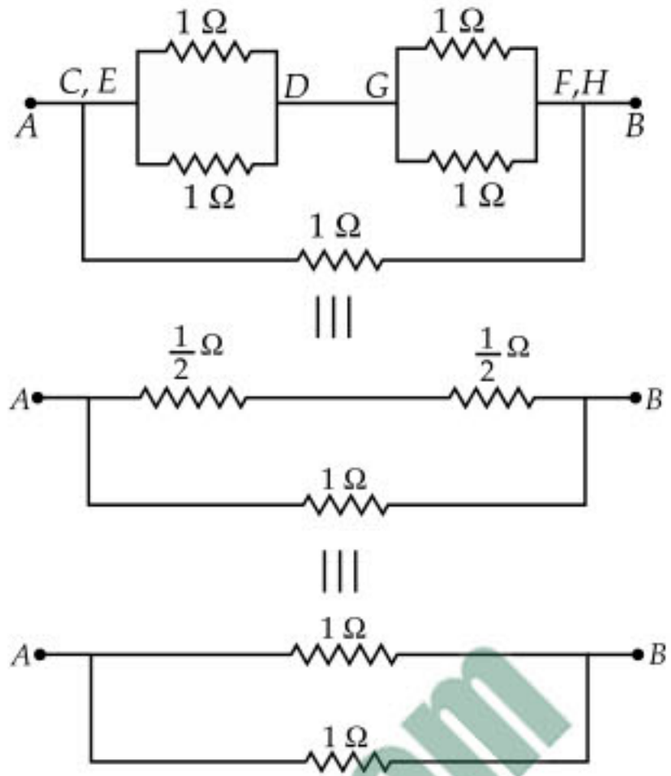
$$R_2 = \frac{\rho(a)}{(4a)(2a)} = \frac{\rho}{8a} \text{ and } R_3 = \frac{\rho(2a)}{(4a)(a)} = \frac{\rho}{2a}$$

$\therefore \quad R_1 > R_3 > R_2$

31. (a) :



The equivalent circuit diagram as shown in the figure.



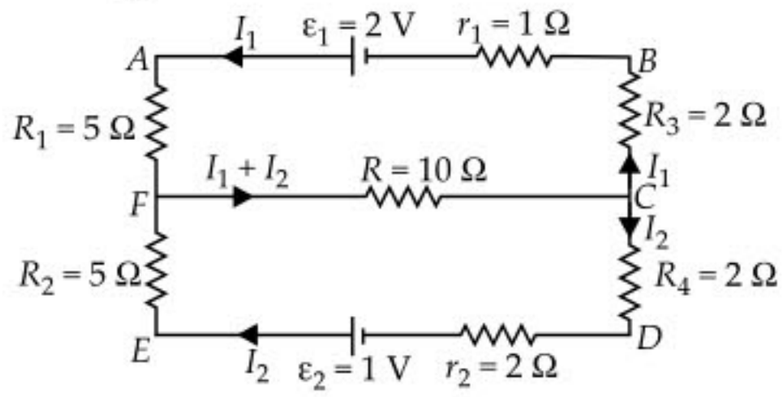
Hence, the equivalent resistance between A and B is

$$\frac{1}{R_{AB}} = \frac{1}{1} + \frac{1}{1} = \frac{2}{1} \quad \frac{1}{R_{AB}} = \frac{1}{2}\Omega$$

32. (a) : The positive terminals of the cells E_1 and E_2 are connected to the wire AE of resistance 10 Ω and negative terminals to the wire BD of resistance 4 Ω. The resistance of 10 Ω is connected between the middle points F and C of the wires AE and BD respectively. Therefore

$$R_1 = R_2 = \frac{10}{2} = 5\,\Omega;\ R_3 = R_4 = \frac{4}{2} = 2\,\Omega$$

The distribution of currents in various branches is shown in the figure.



In closed part $ABCFA$ of the circuit

$$I_1 \times r_1 + I_1 \times R_1 + (I_1 + I_2)R + I_1 \times R_3 = \varepsilon_1$$

$$I_1 \times 1 + I_1 \times 5 + (I_1 + I_2) \times 10 + I_1 \times 2 = 2$$

or $\quad 9I_1 + 5I_2 = 1 \qquad \ldots(i)$

In the closed part $CDEFC$ of the circuit

$$I_2 \times r_2 + I_2 \times R_2 + (I_1 + I_2) \times R + I_2 \times R_4 = \varepsilon_2$$

or $\quad I_2 \times 2 + I_2 \times 5 + (I_1 + I_2) \times 10 + I_2 \times 2 = 1$

or $\quad 10I_1 + 19I_2 = 1 \qquad \ldots(ii)$

Solving equations (i) and (ii), we have

$$I_1 = \frac{14}{121}\text{A and } I_2 = -\frac{1}{121}\text{ A}$$

Therefore, current through resistance R,

$$I_1 + I_2 = \frac{14}{121} + \left(-\frac{1}{121}\right) = \frac{13}{121}\text{ A}$$

Potential difference across the resistance, R

$$= (I_1 + I_2)R = \frac{13}{121}\times10 = 1.0744\text{ V}$$

33. (c) : $R'_A = R_A(1+\alpha_A\Delta T)$

$R'_B = R_B(1+\alpha_B\Delta T)$

$R' = R_A(1+\alpha_A\Delta T) + R_B(1+\alpha_B\Delta T)$

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From given condition,

$R_A(1+\alpha_A\Delta T)+R_B(1+\alpha_B\Delta T)=R_A+R_B$

$$\frac{\rho_A l_A}{A_A}\alpha_A+\frac{\rho_A l_B}{A_B}\alpha_B=0 \Rightarrow \frac{l_A}{l_B}=\frac{3}{10}$$

34. (a) : Effective resistance R_p of 4 Ω, 6 Ω and 12 Ω in parallel will be

$$\frac{1}{R_p}=\frac{1}{4}+\frac{1}{6}+\frac{1}{12}=\frac{6}{12}=\frac{1}{2} \text{ or } R_p=2\ \Omega$$

Total resistance of circuit = 2 + 2 = 4 Ω

The battery current, $I=\frac{4}{4}=1$ A

35. (c) : The current flowing through the circuit is given by $I=\frac{n\varepsilon}{R+nr}$ so when $R \ll nr$, $I=\frac{\varepsilon}{r}$ = current due to single Cell, when $R \gg nr$, $I=\frac{n\varepsilon}{R}=n$ times the current due to single cell. Thus when cell are connected in series, we get maximum current where total internal resistance of the cells is negligible.

36. (b) : Given, $R_1 : R_2 = 1 : 2$

The equivalent resistance of parallel combination

$$\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}=\frac{1}{R_1}+\frac{1}{2R_1}+\frac{1}{R_3}$$

or $$\frac{1}{R_3}=\frac{1}{R}-\frac{3}{2R_1}=1-\frac{3}{2R_1}$$

or $$1=R_3-\frac{3R_3}{2R_1} \text{ or } R_3=1+\frac{3R_3}{2R_1}$$

Since no resistance value is fractional, therefore, minimum value of $\frac{R_3}{R_1}$ is $\frac{2}{3}$.

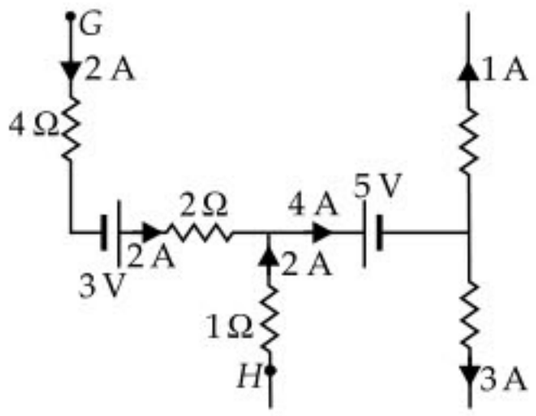
So, $R_3 = 1 + 1 = 2\ \Omega$

and $R_1 = 3\ \Omega$

So maximum resistance value,

$R_2 = 2R_1 = 6\ \Omega$

37. (c) : The current distribution in a circuit is as shown in the figure.



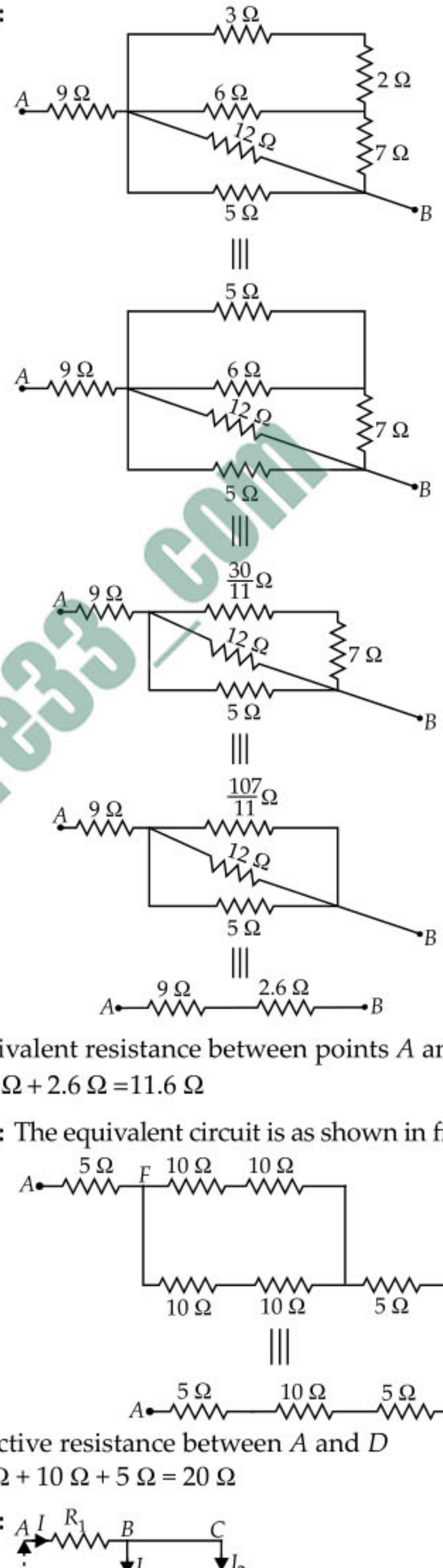
Let V_G and V_H be the potentials at points G and H respectively.

$\therefore\ V_G-(2\text{ A})(4\ \Omega)+3\text{ V}-(2\text{ A})(2\ \Omega)+(2\text{ A})(1\ \Omega)=V_H$

$V_G-8\text{ V}+3\text{ V}-4\text{ V}+2\text{ V}=V_H$

$V_G-V_H=7\text{ V}$

38. (b) :



The equivalent resistance between points A and B is

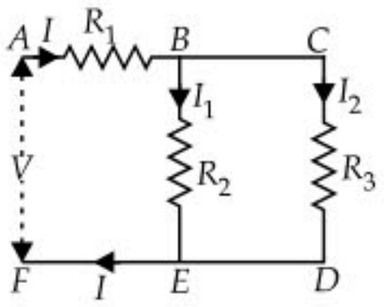
$R_{AB}=9\ \Omega+2.6\ \Omega=11.6\ \Omega$

39. (b) : The equivalent circuit is as shown in figure.

$\therefore$ Effective resistance between A and D

$= 5\ \Omega + 10\ \Omega + 5\ \Omega = 20\ \Omega$

40. (c) :



As voltage across the resistors R_2 and R_3 is same and they show same dissipationof energy, so using the relation for energy, $H=\frac{V^2}{R}t$, we get $R_2 = R_3$.

Thus, the current in each resistor R_2 and R_3 will be $\frac{I}{2}$.

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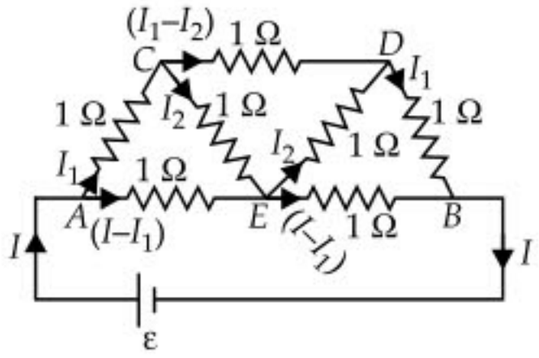
$i.e.,\ I_1 = \frac{I}{2}$ and $I_2 = \frac{I}{2}$

Since the energy dissipation is same in all the three resistors, so

$I^2R_1t = I_{21}R_2t$ or $I^2R_1t = \left(\frac{I}{2}\right)^2 R_2t$ or $R_1 = \frac{R_2}{4}$

41. (c)

42. (c) : Let a cell of emf ε be connected between A and B. The currents through the various arms will be as shown in the figure.



Applying Kirchhoff's loop law in closed loop $ACEA$, we get

$-I_1 - I_2 + (I - I_1) = 0$

$I = 2I_1 + I_2$ ...(i)

Again applying Kirchhoff's loop law in closed $CEDC$, we get

$-I_2 - I_2 + (I_1 - I_2) = 0$

or $3I_2 = I_1$

Putting this value in (i), we get

$I = 2I_1 + \frac{I_1}{3}$ or $I_1 = \left(\frac{3}{7}\right)I$

Again applying Kirchhoff's loop law in closed loop $AEBA$, we get

$-(I - I_1) - (I - I_1) + \varepsilon = 0$

$\varepsilon = 2(I - I_1)$

$\varepsilon = 2\left(I - \frac{3I}{7}\right) = \frac{8I}{7}$

If R is the effective resistance between A and B, then $\varepsilon = IR$

So $IR = \frac{8I}{7}$ or $R = \frac{8}{7}\Omega$

43. (d) : Resistance of arm $AFE = 3 + 3 = 6\ \Omega$

The arms AFE and AE are in parallel, their effective resistance $= \frac{6\times6}{6+6} = 3\ \Omega$

Resistance of arm $AED = 3 + 3 = 6\ \Omega$

Effective resistance between A and D of portion $AFED$ $= \frac{6\times6}{6+6} = 3\ \Omega$

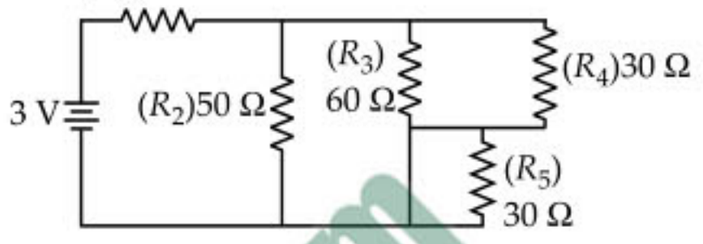
Effective resistance between A and C of portion $AFEDC = \frac{(3+3)\times6}{(3+3)+6} = 3\ \Omega$

Resistance of arm $AFEDCB = 3 + 3 = 6\ \Omega$

For resistance between A and B, 6 Ω and 3 Ω are in parallel.

Thus effective resistanc $R_p = \frac{3\times6}{3+6} = 2\ \Omega$

44. (a) :



Here (R_3) 60 Ω and $(R_4)30\ \Omega$ are in parallel. Their combination is in series with (R_5) 30 Ω resistance. Their effective resistance is

$= \frac{60\times30}{60+30} + 30\ \Omega = 20 + 30 = 50\ \Omega$

It is in parallel with resistance $(R_2)50\ \Omega$ with together is in series with $(R_1)50\ \Omega$. The effective resistance of the circuit is

$= 50 + \frac{50\times50}{50+50} = 50 + 25 = 75\ \Omega$

Current in the circuit is

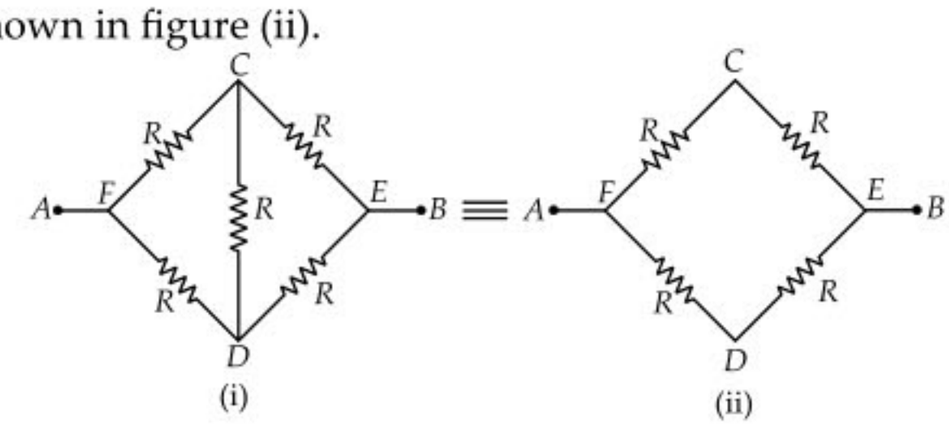
$I = \frac{3\ \text{V}}{75\ \Omega} = \frac{1}{25}\ \text{A}$

Current through $R_5 = \frac{1}{2}\times\frac{1}{25} = \frac{1}{50}\ \text{A}$

Current through $R_4 = \frac{2}{3}\times\frac{1}{50} = \frac{1}{75}\ \text{A}$

Potential difference across $R_4 = 30\times\frac{1}{75} = 0.4\ \text{V}$

45. (c) : The equivalent circuit is as shown in figure (i), which is a balanced Wheatstone bridge. There will be no current in arm CD. Hence the effective circuit will be as shown in figure (ii).



The resistance of arm $AFCEB = R + R = 2R$.

When a potential difference V is applied across A and B, then current in arm $AFCEB$ is $I = \frac{V}{2R}$.

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Moving Charges and Magnetism

Magnetic Field

The discovery in 1819 by professor Oersted at the university of Copenhagen that an electric current is accompanied by magnetic effect saw the birth of electromagnetism.

The space surrounding a magnet where a magnetic force is experienced is called a magnetic field.

The sources of magnetic fields are:

- a current carrying conductor
- changing electric field
- moving charged particle
- permanent magnet and electromagnet etc.

Magnetic field is denoted by symbol B. It is also called magnetic induction or magnetic flux density.

Magnetic field is a vector quantity and its dimensional formula is $[ML^0T^{-2}A^{-1}]$.

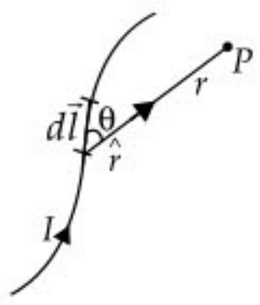
The SI unit of magnetic field is tesla (T) or weber metre^{-2} (Wb m^{-2}). The CGS unit of magnetic field is gauss (G).

$$1 \text{ tesla} = 10^4 \text{ gauss}$$

Conventionally, the direction of the field perpendicular to the plane of the paper is represented by $\otimes$ if into the page, and by $\odot$ if out of the page.

Biot Savart's Law

Biot Savart law gives the magnetic field at some point in space in terms of the current that produces the field.



According to this law, the magnetic field at a point P associated with a length element $d\vec{l}$ of a wire carrying current I, at a distance r from the element is given by

$$dB = \frac{\mu_0 I dl \sin\theta}{4\pi r^2}$$

or $$d\vec{B} = \frac{\mu_0}{4\pi} I \frac{(d\vec{l} \times \vec{r})}{r^3}$$

Here, μ_0 is called permeability of free space. In SI unit the value of $\frac{\mu_0}{4\pi}$ is equal to 10^{-7} $\frac{\text{tesla meter}}{\text{ampere}}$.

Applications of Biot Savart's Law

- **Magnetic field at the centre of a current carrying circular coil**

The magnetic field at the centre of a circular coil of radius a carrying current I is

$$B = \frac{\mu_0}{4\pi} \frac{2\pi I}{a} = \frac{\mu_0 I}{2a}$$

If the circular coil consists of N turns, then

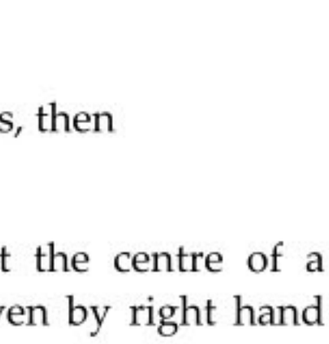
$$B = \frac{\mu_0}{4\pi} \frac{2\pi NI}{a} = \frac{\mu_0 NI}{2a}$$

The direction of magnetic field at the centre of a circular coil carrying current is given by right hand rule. According to which, the direction of magnetic field at the centre of the circular coil is perpendicular to the plane of coil downwards for the clockwise current, and perpendicular to the plane of coil outwards for the anticlockwise current.

The magnetic field at the common centre O of two concentric coils of radii a and b having turns N_1 and N_2 in which the same current I is flowing

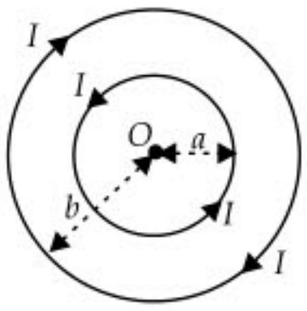
- when current flows in the same direction

$$B = \frac{\mu_0 I}{2}\left[\frac{N_1}{a} + \frac{N_2}{b}\right]$$



- when current flows in the opposite direction

$$B = \frac{\mu_0 I}{2}\left[\frac{N_1}{a} - \frac{N_2}{b}\right]$$



- **Magnetic field at a point on the axis of a circular current carrying coil**

The magnetic field at a point on the axis of the circular current carrying coil is

$$B = \frac{\mu_0}{4\pi} \frac{2\pi NIa^2}{(a^2 + x^2)^{3/2}}$$

where a is the radius of coil, x is the distance of the point on the axis from the centre of the coil, N is the number of turns in the coil.

Special cases :

- If the point lies at the centre of the coil, *i.e.* $x = 0$, then

$$B = \frac{\mu_0}{4\pi} \frac{2\pi NIa^2}{(a^2)^{3/2}} = \frac{\mu_0}{4\pi} \frac{2\pi NI}{a} = \frac{\mu_0 NI}{2a}$$

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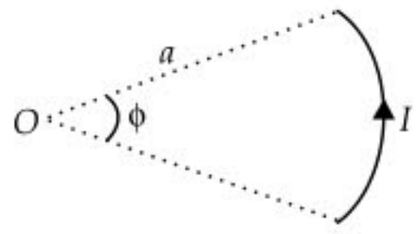
- If $x >> a$, then

$$B = \frac{\mu_0}{4\pi}\frac{2\pi NIa^2}{x^3} = \frac{\mu_0}{4\pi}\frac{2NIA}{x^3} = \frac{\mu_0}{4\pi}\frac{2M}{x^3}$$

where $NIA = M$ = magnetic dipole moment of current loop, A = cross sectional area of loop.

- **Magnetic field at the centre due to current carrying circular arc**

The magnetic field at the centre O of the circular arc of radius a carrying current I is



$$B = \frac{\mu_0 I\phi}{4\pi a}$$

Ampere's Law

According to this law, the line integral of a magnetic field over a closed path $(\oint \vec{B}\cdot d\vec{l})$ is equal to μ_0 times the net current enclosed by that path.

$$i.e.,\ \oint \vec{B}\cdot d\vec{l} = \mu_0 I_{net}$$

Positive direction of current and the direction of the line integral are given by the right hand thumb and curling fingers respectively.

Applications of Ampere's Law

- **Magnetic field due to infinitely long straight cylindrical wire**

Magnetic field due to an infinitely long straight cylindrical wire of radius R, carrying current I at a point distant r from the axis of the wire is given as follows :

At a point outside the wire *i.e.* $(r > R)$ is

$$B = \frac{\mu_0 I}{2\pi r}$$

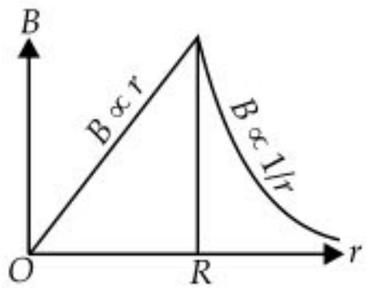
At a point inside the wire *i.e.* $(r < R)$ is

$$B = \frac{\mu_0 Ir}{2\pi R^2}$$

At a point on the surface of a wire *i.e.* $(r = R)$ is

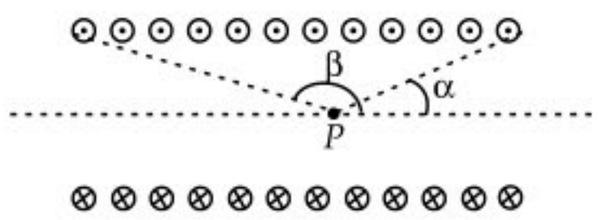
$$B = \frac{\mu_0 I}{2\pi R}$$

The variation of magnetic field B with the distance r from axis is as shown in the figure below.



Solenoid

A solenoid consists of a long insulating wire closely wound in the form of a helix. Its length is very large as compared to its diameter.



The magnetic field at a point P on the axis of the solenoid having n turns per unit length is

$$B = \frac{\mu_0 nI}{2}(\cos\alpha - \cos\beta)$$

Special cases :

- If the solenoid is of infinite length and point P lies near the middle of a solenoid, then

$$\alpha = 0°,\ \beta = 180° \quad \therefore \quad B = \mu_0 nI$$

- If the solenoid is of infinite length and point is near one end, then

$$\alpha = 0°,\ \beta = \frac{\pi}{2} \quad \therefore \quad B = \frac{\mu_0 nI}{2}$$

Motion of a Charged Particle in a Uniform Magnetic Field

In uniform magnetic field, force experienced by a moving uniform charged particle is given by

$$\vec{F} = q(\vec{v}\times\vec{B}) = qvB\sin\theta$$

Here, $\vec{v}$ is the velocity of the particle and $\vec{B}$ is uniform magnetic field and θ is the angle between $\vec{v}$ and $\vec{B}$.

The following conclusions are drawn from the above expression:

- Stationary charge $(i.e.\ \vec{v} = 0)$ experiences no magnetic force.
- If $\vec{v}$ is parallel or antiparallel to $\vec{B}$ then the charged particle experiences no magnetic force.
- As magnetic force is always perpendicular to $\vec{v}$, it does not deliver any power to the charged particle.
- Magnetic force is always perpendicular to both $\vec{v}$ and $\vec{B}$.
- On the basis of expression $\vec{F} = q(\vec{v}\times\vec{B})$ the maximum value of magnetic force is equal to qvB, which occurs when the charge particle is projected perpendicular to the uniform magnetic field.
- In this case, path of charged particle is circular and magnetic force provides the necessary centripetal force.
- If radius of the circular path is R, then

$\frac{mv^2}{R} = qvB$, where m is the mass of the particle.

$$R = \frac{mv}{qB}$$

- Time taken to complete one revolution is

$$T = \frac{2\pi R}{v} \quad \text{or} \quad T = \frac{2\pi m}{qB}$$

If the charged particle is projected obliquely to the field then its velocity $\vec{v}$ can be resolved into two components; one along $\vec{B}$ say $v_{||}$ and the other perpendicular to $\vec{B}$ say $v_\perp$. It experiences a magnetic force and hence has a tendency to move on a circular path. Due to $v_{||}$ it experience no force, and hence has a tendency to move on a straight path along the field. So, in this case it moves along a helical path.

- Radius of the helix is $R = \frac{mv_\perp}{qB}$.
- Time taken to complete one revolution is $T = \frac{2\pi m}{qB}$.

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- The distances moved by the charged particle along the magnetic field during one revolution is called pitch.

$$\text{Pitch} = v_{||} \times T = \frac{2\pi}{qB} m v_{||}$$

- **Motion of a charged particle in a uniform electric field**

  When a charged particle of charge q moving or at rest is subjected to a uniform electric field $\vec{E}$, the force acting on it is

$$\vec{F} = q\vec{E}$$

- The direction of $\vec{F}$ is same as that of $\vec{E}$, if q is +ve and $-\vec{E}$ if q is –ve.
- **Motion of charged particle in combined uniform electric and magnetic fields**

  When a charged particle of charge q moving with velocity $\vec{v}$ is subjected to an electric field $\vec{E}$ and magnetic field $\vec{B}$, the total force acting on the particle is

$$\vec{F} = \vec{F}_E + \vec{F}_M = q\vec{E} + q(\vec{v} \times \vec{B}) = q(\vec{E} + \vec{v} \times \vec{B})$$

  This force is known as Lorentz force and is named after the Dutch physicist Hendrik Antoon Lorentz.

Cyclotron

It is a heavy particle accelerator, invented in 1929 by E.O. Lawrence for accelerating charged particles such as protons, deuterons, or alpha particles in the uniform magnetic field upto energy of the order of MeV.

$$\text{Cyclotron frequency } \upsilon = \frac{Bq}{2\pi m}$$

where m and q are mass and charge of the particle and B is the strength of magnetic field.

- **Force on a current carrying wire in a magnetic field**

  When a straight conductor of length l carrying current I is placed in magnetic field, it experiences a force is given by

$$F = I(\vec{l} \times \vec{B}) = IlB\sin\theta$$

  Here, θ is angle between $\vec{l}$ and $\vec{B}$.
- **Fleming's left hand rule**

  The direction of the force $\vec{F} = I(\vec{l} \times \vec{B})$ is given by the Fleming's left hand rule. Close your left hand first and then shoot your index finger in the direction of the magnetic field. Relax your middle finger in the direction of current. The force on the conductor is shown by the direction of the erect thumb.
- **Force between two parallel current carrying wires**

  Two long wires 1 and 2 are kept parallel to each other of distance r and carrying current I_1 and I_2 respectively in the same direction.

  The force per unit length of the wire 2 due to wire 1 is

$$\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r}$$

  The same force acts on wire 1 due to wire 2.

  The wires attract each other if currents in the wires are flowing in the same direction and they repel each other if the currents are in opposite directions.

If two linear current carrying conductors of unequal length are held parallel to each other, then the force on a long conductor is due to magnetic field interaction due to currents of short conductor and long conductor. If l, L be lengths of short and long conductor and I_1, I_2 = currents through short and long conductors respectively and r is the separation between these two parallel conductors, then the force on long conductor

$= \text{force on short conductor} = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r} l.$

When two charges q_1 and q_2 respectively moving with velocities v_1 and v_2 are at a distance r apart, then the force acting between them is

$$F = \frac{\mu_0}{4\pi}\frac{q_1 q_2 v_1 v_2}{r^2}$$

- If q_1 and q_2 are of the same nature and they move in the same direction, then the force acting between them is attractive.
- If q_1 and q_2 are of the same nature and they move in the opposite directions, then the force acting between them is repulsive.
- **Torque on a current carrying coil placed in a uniform magnetic field**

  When a current carrying coil is placed in a uniform magnetic field, the net force on it is always zero but different parts of the coil experience forces in different directions. Due to it, the coil may experience a torque or couple.

  When a coil of area A having N turns, carrying current I is placed in uniform magnetic field B, it will experience torque which is given by

  $\tau = NIAB\sin\theta = MB\sin\theta$

  where $M = NIA$ and θ is the angle between the direction of magnetic field and normal to the plane of the coil.

Special cases:

- If the plane of the coil is perpendicular to the direction of magnetic field *i.e.* $\theta = 0°$, then

$$\tau = 0 \text{ (minimum)}$$

- If the plane of the coil is parallel to the direction of magnetic field *i.e.* $\theta = 90°$, then

$$\tau = NIAB \text{ (maximum)}$$

  If α is the angle between plane of the coil and the magnetic field, then torque on the coil is

$$\tau = NIAB\cos\alpha = MB\cos\alpha$$

Moving Coil Galvanometer

It is an instrument used for detection and measurement of small currents.

- **Principle of a moving coil galvanometer:** When a current carrying coil is placed in a magnetic field, it experiences a torque.

  In moving coil galvanometer the current I passing through the galvanometer is directly proportional to its deflection (θ).

  $I \propto \theta$ or, $I = G\theta$

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where $G = \frac{k}{NAB}$ = galvanometer constant

A = area of a coil, N = number of turns in the coil, B = strength of magnetic field, k = torsional constant of the spring *i.e.* restoring torque per unit twist.

- **Current sensitivity :** It is defined as the deflection produced in the galvanometer, when unit current flows through it.

$$I_s = \frac{\theta}{I} = \frac{NAB}{k}$$

The unit of current sensitivity is rad A^{-1} or div A^{-1}

- **Voltage sensitivity :** It is defined as the deflection produced in the galvanometer when a unit voltage is applied across the two terminals of the galvanometer.

$$V_s = \frac{\theta}{V} = \frac{\theta}{IR} = \frac{NAB}{kR}$$

The unit of voltage sensitivity is rad V^{-1} or div V^{-1}

$$V_s = \frac{1}{R} I_s$$

Ammeter

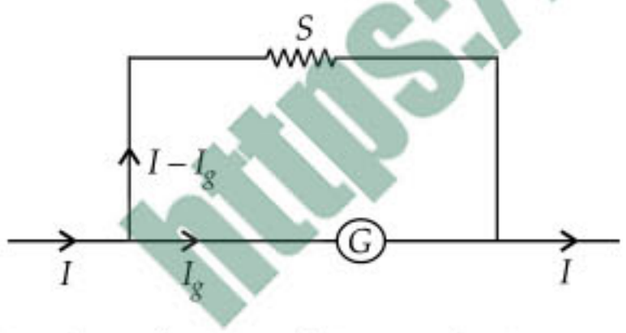
It is an instrument used to measure current in an electrical circuit.

- **Conversion of galvanometer into a ammeter**

A galvanometer can be converted into an ammeter of given range by connecting a suitable low resistance S called shunt in parallel to the given galvanometer, whose value is given by

$$S = \left(\frac{I_g}{I - I_g}\right) G$$

where I_g is the current for full scale deflection of galvanometer, I is the current to be measured by the galvanometer and G is the resistance of galvanometer.



Ammeter is a low resistance instrument and it is always connected in series to the circuit. An ideal ammeter has zero resistance.

In order to increase the range of an ammeter n times, the value of shunt resistance to be connected in parallel is $S = G/(n-1)$.

Voltmeter

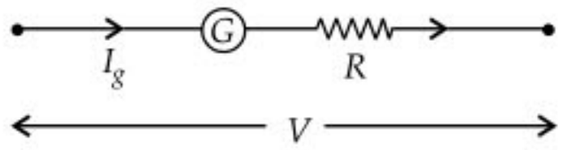
It is an instrument used to measure potential difference across any element in an electrical circuit.

- **Conversion of galvanometer into voltmeter**

A galvanometer can be converted into voltmeter of given range by connecting a suitable resistance R in series with the galvanometer, whose value is given by

$$R = \frac{V}{I_g} - G$$

where V is the voltage to be measured, I_g is the current for full scale deflection of galvanometer and G is the resistance of galvanometer.

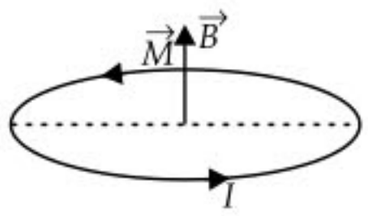


Voltmeter is a high resistance instrument and it is always connected in parallel with the circuit element across which potential difference is to be measured. An ideal voltmeter has infinite resistance.

In order to increase the range of voltmeter n times the value of resistance to be connected in series with galvanometer is $R = (n-1)G$.

- **Current Loop as a Magnetic Dipole**

Any current carrying loop (of any shape) behaves as a magnetic dipole whose magnetic moment is,



$$\vec{M} = I\vec{A}$$

Here I is current through the loop and $\vec{A}$ the surface area of the loop.

A current carrying coil having N turns, then magnetic moment $\vec{M}$ of dipole, $\vec{M} = NI\vec{A}$

- **Magnetic dipole moment**

It is defined as the product of strength of either pole (m) and the magnetic length $(2\vec{l})$ of the magnet. It is denoted by $\vec{M}$.

Magnetic dipole moment = strength of either pole × magnetic length

$$\vec{M} = m(2\vec{l})$$

Magnetic dipole moment is a vector quantity and it is directed from south to north pole of the magnet.

The SI unit of magnetic dipole moment is A m^2.

If a magnet of moment M and pole strength m is cut into two equal parts along its length, then the pole strength of each part is $m/2$ and the magnetic moment of each part is $M/2$.

If a magnet of magnetic moment M and pole strength m is cut into two equal halves along perpendicular to its length, then the pole strength of each part is m and magnetic moment of each part is $M/2$.

- **Magnetic field at a point due to magnetic dipole (or bar magnet)**

The magnetic field due to a bar magnet at any point on the axial line (end on position) is given by

$$B_{axial} = \frac{\mu_0}{4\pi} \frac{2Mr}{(r^2 - l^2)^2}$$

where r = distance between the centre of the magnet and the given point on the axial line, $2l$ = magnetic length of the magnet and M = magnetic moment of the magnet.

For short magnet, $l^2 << r^2$

$$B_{axial} = \frac{\mu_0 2M}{4\pi r^3}$$

The direction of B_{axial} is along SN.

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The magnetic field due to a bar magnet at any point on the equatorial line (board-side on position) of the bar magnet is given by

$$B_{\text{equatorial}} = \frac{\mu_0 M}{4\pi(r^2 + l^2)^{3/2}}$$

For short magnet, $l^2 << r^2$

$$B_{\text{equatorial}} = \frac{\mu_0 M}{4\pi r^3}$$

The direction of $B_{\text{equatorial}}$ is parallel to NS.

- **Torque on a magnetic dipole placed in a uniform magnetic field**

When a magnetic dipole of dipole moment $\vec{M}$ is placed in a uniform magnetic field $\vec{B}$, it will experience a torque and is given by

$$\vec{\tau} = \vec{M} \times \vec{B} \quad \text{or} \quad \tau = MB\sin\theta$$

where θ is the angle between $\vec{M}$ and $\vec{B}$.

Torque acting on a dipole is maximum ($\tau_{max} = MB$) when dipole is perpendicular to the field and minimum ($\tau = 0$) when dipole is parallel or antiparallel to the field.

When a dipole is placed in a uniform magnetic field, it will experience only torque and the net force on the dipole is zero while when it is placed in a non uniform magnetic field, it will experience both torque and net force.

- **Magnetic moment of an orbiting electron and bohr magneton**

An electron revolving in its orbit is equivalent to a current $I = \frac{ev}{2\pi r}$,

where r = radius of electron orbit and v = electron orbital speed.

The magnetic moment produced due to orbital motion of electron is

$$\text{or} \quad M_e = IA = \frac{ev}{2\pi r} \cdot \pi r^2 = \frac{evr}{2} \quad \text{or} \quad M_e = \frac{eh}{4\pi m} \cdot n$$

where $n = 1, 2, 3, 4, ...$

Minimum value of magnetic moment of an orbiting electron, responding to $n = 1$, is called Bohr magneton (μ_B) and has a value

$$\mu_B = \frac{eh}{4\pi m} = 9.27 \times 10^{-24} \text{ A m}^2$$

- **Gauss's law for magnetism**

Gauss's law for magnetism states that the net magnetic flux through any closed surface is zero.

$$\phi = \sum_{\substack{\text{all area} \\ \text{elements } \Delta S}} \vec{B} \cdot \Delta\vec{S} = 0$$

This law establishes that isolated magnetic poles do not exist.

- **Magnetic intensity**

When a magnetic material is placed in a magnetic field, it becomes magnetised. The capability of the magnetic field to magnetise a material is expressed by means of a magnetic vector $\vec{H}$, called the magnetic intensity of the field. The relation between magnetic induction B and magnetising field H is

$$B = \mu H$$

where μ is the permeability of medium.

It is a vector quantity and its SI unit is A m^{-1}.

- **Intensity of magnetisation**

It is defined as the magnetic moment per unit volume.

$$I = \frac{\text{Magnetic moment}}{\text{Volume}} = \frac{M}{V}$$

If A = uniform area of cross-section of the magnetised specimen (a rectangular bar)

$2l$ = magnetic length of the specimen

m = strength of each pole of the specimen,

$$I = \frac{m \times 2l}{A \times 2l} = \frac{m}{A}$$

The intensity of magnetisation is a vector quantity and its SI unit is A m^{-1}. Its dimensional formula is $[M^0L^{-1}T^0A]$.

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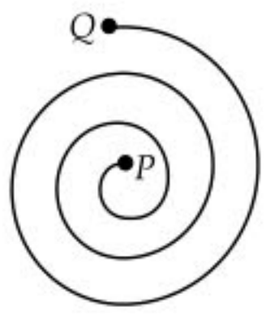
EXAM DRILL

1. A wire of length l is formed into a circular loop of one turn only and is suspended in a magnetic field B. When a current I is passed through the loop, the torque experienced by it is

(a) $\left(\frac{1}{4\pi}\right)BIl$ (b) $\left(\frac{1}{4\pi}\right)l^2IB$

(c) $\left(\frac{1}{4\pi}\right)B^2Il$ (d) $\left(\frac{1}{4\pi}\right)BI^2l$

2. A charged particle enters into a region which offers a resistance against its motion and uniform magnetic field exists in the region. The particle traces a spiral path as shown in the figure. Which of the following statements is correct?



(a) Component of the magnetic field in the plane of spiral is zero.
(b) Particle enters in the region at Q.
(c) If the magnetic field is outward then the particle is positively charged.
(d) All of the above.

3. The magnetic potential due to a magnetic dipole at a point on its axis distant 40 cm from its centre is found to be 2.4×10^{-5} J A^{-1} m^{-1}. The magnetic moment of the dipole will be

(a) 28.6 A m^2 (b) 32.2 A m^2
(c) 38.4 A m^2 (d) 22.2 A m^2

4. A circular coil of radius R carries an electric current. The magnetic field due to the coil at a point on the axis of the coil located at a distance r from the centre of the coil such that $r >> R$, varies as

(a) $\frac{1}{r}$ (b) $\frac{1}{r^{1/2}}$ (c) $\frac{1}{r^2}$ (d) $\frac{1}{r^3}$

5. 10 mA current can pass through a galvanometer of resistance 25 Ω. What resistance in series should be connected through it, so that it is converted into a voltmeter of 100 V?

(a) 0.975 Ω (b) 99.75 Ω (c) 975 Ω (d) 9975 Ω

6. An electron is revolving around a proton in a circular path of diameter 0.1 nm. It produces a magnetic field 14 T at a proton. Then the angular speed of the electron is

(a) 8.8×10^{16} rad s^{-1} (b) 4.4×10^{16} rad s^{-1}
(c) 2.2×10^{16} rad s^{-1} (d) 1.1×10^{16} rad s^{-1}

7. A closed loop lying in the x-y plane carries a current. If a uniform magnetic field B is present in the region, the force acting on the loop will be zero, if B is in

(a) the y-direction (b) the z- direction
(c) the x- direction
(d) any of the above directions

8. A circular loop of radius 0.0157 m carries a current of 2.0 A. The magnetic field at the centre of the loop is $[\mu_0 = 4\pi \times 10^{-7}$ Wb A^{-1} m$^{-1}]$

(a) 1.57×10^{-5} Wb m^{-2} (b) 8.0×10^{-5} Wb m^{-2}
(c) 2.0×10^{-5} Wb m^{-2} (d) 3.14×10^{-5} Wb m^{-2}

9. A coil having N turns is wound tightly in the form of a spiral with inner and outer radii a and b respectively. When a current I passes through the coil, the magnetic field at the centre is

(a) $\frac{\mu_0 NI}{b}$ (b) $\frac{2\mu_0 NI}{a}$

(c) $\frac{\mu_0 NI}{2(b-a)}\ln\frac{b}{a}$ (d) $\frac{\mu_0 NI}{2(b-a)}\ln\frac{a}{b}$

10. A charged particle is moving along a magnetic field line. The magnetic force on the particle is

(a) along its velocity
(b) opposite to its velocity
(c) perpendicular to its velocity
(d) zero

11. Magnetic field at the centre of a circular loop of area A is B. The magnetic moment of the loop will be

(a) $\frac{BA^2}{\mu_0\pi}$ (b) $\frac{BA^{3/2}}{\mu_0\pi}$

(c) $\frac{BA^{3/2}}{\mu_0\pi^{1/2}}$ (d) $\frac{2BA^{3/2}}{\mu_0\pi^{1/2}}$

12. The distance at which the magnetic field on axis as compared to the magnetic field at the centre of the coil carrying current I and radius R is 1/8, would be

(a) R (b) $\sqrt{2}R$ (c) $2R$ (d) $\sqrt{3}R$

13. A proton and an α-particle, moving with the same velocity, enter into a uniform magnetic field, acting normal to the plane of their motion. The ratio of the radii of the circular paths described by the proton and α-particle is

(a) 1 : 2 (b) 1 : 4 (c) 1 : 16 (d) 4 : 1

14. An electron is moving on a circle of radius 0.5 Å with a frequency of 5×10^{16} Hz in anti-clockwise direction. The equivalent loop-current is

(a) 4.0 mA (clockwise)
(b) 4.0 mA (anti-clockwise)
(c) 8.0 mA (clockwise)
(d) 8.0 mA (anti-clockwise)

15. A particle having a mass of 10^{-2} kg carries a charge of 5×10^{-8} C. The particle is given an initial horizontal velocity of 10^5 m s^{-1} in the presence of electric field $\vec{E}$ and magnetic field $\vec{B}$. To keep the particle moving in a horizontal direction, it is necessary that

(1) $\vec{B}$ should be perpendicular to the direction of velocity and $\vec{E}$ should be along the direction of velocity.
(2) Both $\vec{B}$ and $\vec{E}$ should be along the direction of velocity.
(3) Both $\vec{B}$ and $\vec{E}$ are mutually perpendicular and perpendicular to the direction of velocity.

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(4) $\vec{B}$ should be along the direction of velocity and $\vec{E}$ should be perpendicular to the direction of velocity.

Which one of the following pairs of statements is possible?

(a) (1) and (3) (b) (3) and (4)
(c) (2) and (3) (d) (2) and (4)

16. Two very long, straight, parallel wires carry steady currents I and $-I$ respectively. The distance between the wires is d. At a certain instant of time, a point charge q is at a point equidistant from the two wires, in the plane of the wires. Its instantaneous velocity $\vec{v}$ is perpendicular to the plane of wires. The magnitude of the force due to the magnetic field acting on the charge at this instant is

(a) $\frac{\mu_0 Iqv}{2\pi d}$ (b) $\frac{2\mu_0 Iqv}{\pi d}$
(c) $\frac{\mu_0 Iqv}{\pi d}$ (d) zero

17. In a galvanometer 5% of the total current in the circuit passes through it. If the resistance of the galvanometer is G, the shunt resistance S connected to the galvanometer is

(a) $19G$ (b) $\frac{G}{19}$ (c) $20G$ (d) $\frac{G}{20}$

18. An equilateral triangular loop is made up of wire of uniform resistance. A current I enters through one of the vertices of triangle and exists from other vertices of the triangle of side a as shown in figure.

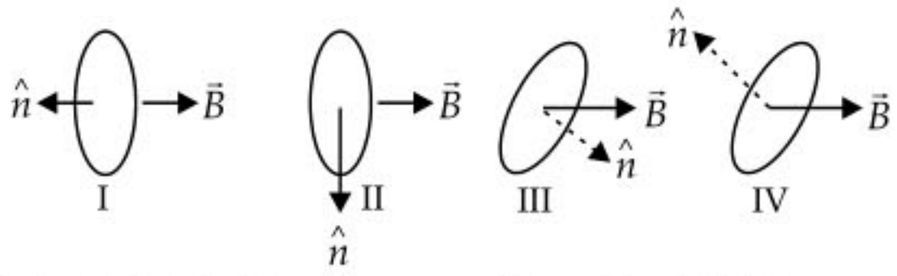
The magnitude of magnetic field at the centre of the equilateral triangle loop is

(a) $\frac{3\mu_0 I}{2\pi a}$ (b) $\frac{9\mu_0 I}{2\pi a}$
(c) $\frac{3\sqrt{3}\mu_0 I}{2\pi a}$ (d) zero

19. A wire of length 6.28 m is bent into a circular coil of 2 turns. If a current of 0.5 A exists in the coil, the magnetic moment of the coil is

(a) $\frac{\pi}{4}$ A m^2 (b) $\frac{1}{4}$ A m^2
(c) π A m^2 (d) 4π A m^2

20. A current carrying loop is placed in a uniform magnetic field in four different orientations I, II, III and IV, as shown in the figure. Arrange them in the decreasing order of potential energy.

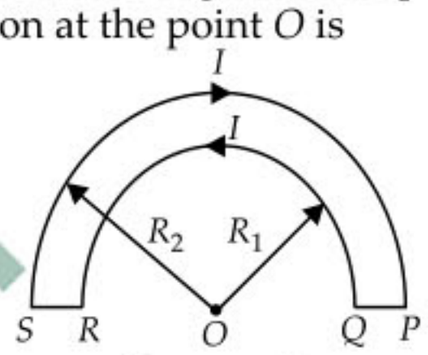


(a) I, IV, II, III (b) III, II, IV, I
(c) II, III, IV, I (d) I, II, III, IV

21. Two ions having equal masses but charges in the ratio 1 : 2 are projected perpendicular to a uniform magnetic field with speeds in the ratio 2 : 3. The ratio of the radii of the circular paths along which the two ions move is

(a) 4 : 3 (b) 2 : 3 (c) 3 : 2 (d) 1 : 4

22. A wire loop $PQRSP$ is constructed by joining two semi-circular coils of radii R_1 and R_2 respectively as shown in the figure. If the current flowing in the loop is I, then the magnetic induction at the point O is



(a) $\frac{\mu_0 I}{4}\left[\frac{1}{R_1}-\frac{1}{R_2}\right]$
(b) $\frac{\mu_0 I}{4}\left[\frac{1}{R_1}+\frac{1}{R_2}\right]$
(b) $\frac{\mu_0 I}{2}\left[\frac{1}{R_1}-\frac{1}{R_2}\right]$ (d) $\frac{\mu_0 I}{2}\left[\frac{1}{R_1}+\frac{1}{R_2}\right]$

23. A charged particle with velocity $\vec{v} = x\hat{i} + y\hat{j}$ moves in a magnetic field $\vec{B} = y\hat{i} + x\hat{j}$. Magnitude of the force acting on the particle is F. The correct option for F is

(1) No force will act on particle if $x = y$
(2) Force will act along y axis if $y < x$
(3) Force is proportional to $(x^2 - y^2)$ if $x > y$
(4) Force is proportional to $(x^2 + y^2)$ if $y > x$
(a) 1 and 2 are true (b) 1 and 3 are true
(c) 2 and 4 are true (d) 3 and 4 are true

24. A proton of mass 1.67×10^{-27} kg and charge 1.6×10^{-19} C is projected with a speed of 2×10^6 m s^{-1} at an angle of 60° to the x-axis. If a uniform magnetic field of 0.104 T is applied along y-axis, the path of proton is

(a) a circle of radius = 0.2 m and time period $= 2\pi \times 10^{-7}$ s
(b) a circle of radius = 0.1 m and time period $= 2\pi \times 10^{-7}$ s
(c) a helix of radius = 0.1 m and time period $= 2\pi \times 10^{-7}$ s
(d) a helix of radius = 0.2 m and time period $= 2\pi \times 10^{-7}$ s

25. A current loop consists of two identical semicircular parts each of radius R, one lying in the x-y plane and the other in x-z plane. If the current in the loop is I. The resultant magnetic field due to the two semicircular parts at their common centre is

(a) $\frac{\mu_0 I}{2\sqrt{2}R}$ (b) $\frac{\mu_0 I}{2R}$ (c) $\frac{\mu_0 I}{4R}$ (d) $\frac{\mu_0 I}{\sqrt{2}R}$

26. A particle of charge q and mass m moves in a circular orbit of radius r with angular speed ω. The ratio of the magnitude of its magnetic moment to that of its angular momentum depends on

(a) ω and q (b) ωq and m
(c) q and m (d) ω and m

27. A current path shaped as shown in figure produces a magnetic field at P, the centre of the arc. If the arc subtends an angle of 30° and the radius of the arc is

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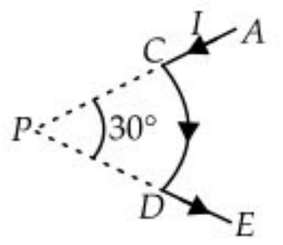
0.6 m. What is the magnitude of the field at P if the current is 3.0 A?

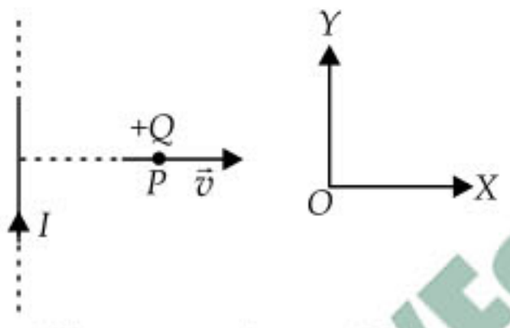


(a) 2.62×10^{-6} T
(b) 2.62×10^{-7} T
(c) 3.62×10^{-7} T
(d) 2.62×10^{-8} T

28. A cyclotron is operated at an oscillator frequency of 24 MHz and has a dee radius R = 60 cm. What is magnitude of the magnetic field B (in tesla) to accelerate deuterons (mass = 3.34×10^{-27} kg)?
(a) 9.5 (b) 7.2
(c) 5.0 (d) 3.2

29. A moving coil galvanometer has 150 equal divisions. Its current sensitivity is 10 divisions per milliampere and voltage sensitivity is 2 divisions per millivolt. In order that each division reads 1 volt, the resistance in ohms needed to be connected in series with the coil will be
(a) 9995 (b) 99995
(c) 10^5 (d) 10^3

30. A very long straight wire carries a current I. At the instant when a charge $+Q$ at point P has velocity $\vec{v}$, as shown, the force on the charge is



(a) along OX (b) opposite to OY
(c) along OY (d) opposite to OX

31. Two current loops (similar) are placed with their planes one along x-axis and the other along y-axis. Then the ratio of resultant magnetic field at a common point on the axis to the individual magnetic field at the same point is
(a) $\sqrt{2}:1$ (b) $1:\sqrt{2}$
(c) $3:2$ (d) $\sqrt{3}:\sqrt{2}$

32. Two very long straight parallel wires carry currents I and $2I$ in opposite directions. The distance between the wires is r. At a certain instant of time a point charge q is at a point equidistant from the two wires in the plane of the wires. Its instantaneous velocity v is perpendicular to the plane of the wires. The magnitude of the force due to the magnetic field acting on the charge at this instant is
(a) zero (b) $\frac{3\mu_0}{2\pi}\frac{Iqv}{r}$
(c) $\frac{\mu_0}{\pi}\frac{Iqv}{r}$ (d) $\frac{\mu_0}{2\pi}\frac{Iqv}{r}$

33. The shunt resistance required to allow 4% of the main current through the galvanometer of resistance 48 Ω is
(a) 1 Ω (b) 2 Ω
(c) 3 Ω (d) 4 Ω

34. A straight wire carrying current I is made into a circular loop. If M is the magnetic moment associated with the loop, then the length of the wire is
(a) $\sqrt{\frac{4\pi M}{I}}$ (b) $\sqrt{\frac{2\pi M}{I}}$
(c) $\sqrt{\frac{\pi M}{I}}$ (d) $\sqrt{\frac{\pi M}{2I}}$

35. A proton carrying 1 MeV kinetic energy is moving in a circular path of radius R in uniform magnetic field. What should be the energy of an α-particle to describe a circle of same radius in the same field?
(a) 2 MeV (b) 1 MeV (c) 0.5 MeV (d) 4 MeV

36. A magnetic needle suspended parallel to a magnetic field requires $\sqrt{3}$ J of work to turn it through 60°. The torque needed to maintain the needle in this position will be
(a) $2\sqrt{3}$ J (b) 3 J
(c) $\sqrt{3}$ J (d) $\frac{3}{2}$ J

37. Magnetic induction at the centre of a circular loop of area π m^2 is 0.1 T. The magnetic moment of the loop is
(a) $\frac{0.1\pi}{\mu_0}$ (b) $\frac{0.2\pi}{\mu_0}$
(c) $\frac{0.3\pi}{\mu_0}$ (d) $\frac{0.4\pi}{\mu_0}$

38. A proton with energy of 2 MeV enters a region of a uniform magnetic field of 2.5 T normally. The magnetic force on the proton is
(Take mass of proton to be 1.6×10^{-27} kg)
(a) 3×10^{-12} N (b) 3×10^{-8} N
(c) 8×10^{-12} N (d) 2×10^{-10} N

39. Two concentric circular coils of ten turns each are situated in the same plane. Their radii are 20 cm and 40 cm and they carry currents 0.2 A and 0.3 A respectively in opposite directions. The magnetic field in tesla at the centre is
(a) $\frac{35}{4}\mu_0$ (b) $\frac{\mu_0}{80}$
(c) $\frac{7}{80}\mu_0$ (d) $\frac{5}{4}\mu_0$

40. The magnetic force acting on a charged particle of charge − 2 μC in a magnetic field of 2T acting in y-direction, when the particle velocity is $\left(2\hat{i}+3\hat{j}\right)\times 10^6$ m s^{-1} is
(a) 4 N in z-direction (b) 8 N in y-direction
(c) 8 N in z-direction (d) 8 N in $-z$ direction

41. The torque required to hold a small circular coil of 10 turns, 2×10^{-4} m^2 area and carrying 0.5 A current in the middle of a long solenoid of 103 turns/m carrying 3 A current with its axis perpendicular to the axis of the solenoid, is
(a) $12\pi \times 10^{-7}$ N m (b) $6\pi \times 10^{-7}$ N m
(c) $4\pi \times 10^{-17}$ N m (d) $2\pi \times 10^{-7}$ N m

42. A tangent galvanometer has a coil of 25 turns and radius of 15 cm. The horizontal component of

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the earth's magnetic field is 3×10^{-5} T. The current required to produce a deflection of 45° in it is

(a) $0 \cdot 29$ A (b) $0 \cdot 14$ A
(c) $1 \cdot 2$ A (d) $3 \cdot 6 \times 10^{-5}$ A

43. A moving coil galvanometer gives full scale deflection, when a current of 0.005 A is passed through its coil. It is converted into a voltmeter reading upto 5 V by connecting an external resistance of 975 Ω in series with it. What is the resistance of the galvanometer coil ?

(a) 30 Ω (b) 25 Ω (c) 50 Ω (d) 40 Ω

44. A thin disc having radius r and charge q distributed uniformly over the disc is rotated n rotations per second about its axis. The magnetic field at the centre of the disc is

(a) $\frac{\mu_0 nq}{2r}$ (b) $\frac{\mu_0 nq}{r}$
(c) $\frac{\mu_0 nq}{4r}$ (d) $\frac{3\mu_0 nq}{4r}$

45. Magnetic field at the centre of a circular loop of area A is B. The magnetic moment of the loop will be

(a) $\frac{BA^2}{\mu_0 \pi}$ (b) $\frac{BA^{3/2}}{\mu_0 \pi}$
(c) $\frac{BA^{3/2}}{\mu_0 \pi^{1/2}}$ (d) $\frac{2BA^{3/2}}{\mu_0 \pi^{1/2}}$

DAY 18 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____

(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (b) : If r is the radius of the loop, then $2\pi r = l$

or $r = \dfrac{l}{2\pi}$

Area of loop, $A = \pi r^2 = \pi\left(\dfrac{l}{2\pi}\right)^2 = \dfrac{l^2}{4\pi}$

Torque on the loop, $\tau = NIAB$

$$\tau = 1 \times I \times \left(\frac{l^2}{4\pi}\right) B = \frac{BIl^2}{4\pi}$$

2. (d) : As the force exerted by the magnetic field is always towards the centre of the path traced and in the plane of the path, hence the magnetic field should be always normal to the plane.

The particle is continuously losing its energy. Hence radius of the path will decrease. Hence particle will enter from Q.

3. (c) : Here, $r = 40\text{ cm} = 0.4\text{ m}$

$\theta = 0°$, $V = 2.4 \times 10^{-5}\text{ J A}^{-1}\text{ m}^{-1}$ (an axial line)

As $V = \dfrac{\mu_0}{4\pi}\dfrac{M\cos\theta}{r^2}$

or $2.4 \times 10^{-5} = 10^{-7}\dfrac{M \times 1}{(0.4)^2}$

$\therefore$ $M = 38.4\text{ A m}^2$

4. (d) : Magnetic field at a point on the axis of a loop is given by

$$B = \frac{\mu_0}{4\pi}\frac{2\pi IR^2}{(R^2 + r^2)^{3/2}}$$

When $r >> R$

$$B = \frac{\mu_0}{4\pi}\frac{2\pi R^2 I}{r^3} = \frac{\mu_0}{2\pi}\frac{AI}{r^3}$$

i.e. $B \propto \dfrac{1}{r^3}$

5. (d) : A galvanometer can be converted into a voltmeter of given range by connecting a suitable resistance R in series of galvanometer, which is given by

$$R = \frac{V}{I_g} - G = \frac{100}{10 \times 10^{-3}} - 25$$

$= 10000 - 25 = 9975\ \Omega$

6. (b) : Here, $2r = 0.1\text{ nm} = 0.1 \times 10^{-9}\text{ m} = 10^{-10}\text{ m}$;

$\therefore$ $r = \dfrac{1}{2} \times 10^{-10}\text{ m}$

$$I = \frac{e}{T} = \frac{e\omega}{2\pi}$$

$$B = \frac{\mu_0}{4\pi}\frac{2\pi I}{r} = \frac{\mu_0}{4\pi}\frac{2\pi}{r}\left(\frac{e\omega}{2\pi}\right) = \frac{\mu_0}{4\pi}\frac{e\omega}{r}$$

or $\omega = B\left(\dfrac{4\pi}{\mu_0}\right) \times \dfrac{r}{e}$

$$= 14 \times \frac{1}{10^{-7}} \times \frac{10^{-10}}{1.6 \times 10^{-19} \times 2}$$

$$= 4.4 \times 10^{16}\text{ rad s}^{-1}$$

7. (d) : A closed current carrying loop of any shape placed in any uniform magnetic field experiences no net force. Therefore, the loop may be lying in any of the directions of magnetic field.

8. (b) : Here, $r = 0.0157\text{ m}$, $I = 2\text{ A}$

$$B = \frac{\mu_0 I}{2r} = \frac{4\pi \times 10^{-7} \times 2}{2 \times 0.0157} = 8 \times 10^{-5}\text{ Wb m}^{-2}$$

9. (c) : Consider an element of thickness dr at a distance r from the centre. The number of turns in this element

$$dN = \left(\frac{N}{b-a}\right) dr$$

Magnetic field due to this element at the centre of the coil will be

$$dB = \frac{\mu_0 (dN) I}{2r} = \frac{\mu_0 I}{2} \cdot \frac{N}{(b-a)} \cdot \frac{dr}{r} \quad \therefore \quad B = \int_{r=a}^{r=b} dB = \frac{\mu_0 NI}{2(b-a)} \ln\left(\frac{b}{a}\right)$$

10. (d) : Force on a charged particle in the magnetic field is

$\vec{F} = q(\vec{v} \times \vec{B})$

Here, $\theta = 0°$ *i.e.*, $\vec{v}$ is parallel to $\vec{B}$ $\therefore$ $\vec{F} =$ zero

11. (d) : Magnetic field at the centre of circuit loop

$$B = \frac{\mu_0}{4\pi}\frac{2\pi I}{r} = \frac{\mu_0 I}{2r} \quad \text{or} \quad I = \frac{2Br}{\mu_0}$$

Also, $A = \pi r^2$ or $r = \left(\dfrac{A}{\pi}\right)^{1/2}$

Magnetic moment,

$$M = IA = \frac{2Br}{\mu_0} A = \frac{2BA}{\mu_0} \times \left(\frac{A}{\pi}\right)^{1/2} = \frac{2BA^{3/2}}{\mu_0 \pi^{1/2}}$$

12. (d) : If a coil of radius R is carrying current I, then magnetic field on its axis at a distance r from its centre is given by

$$B_{axis} = \frac{\mu_0}{4\pi}\frac{2\pi IR^2}{(r^2 + R^2)^{3/2}} \qquad \text{...(i)}$$

At centre,

$$B_{centre} = \frac{\mu_0 I}{2R} \qquad \text{...(ii)}$$

Dividing (i) by (ii), we get

$$\frac{B_{axis}}{B_{centre}} = \frac{\mu_0 IR^2}{2(r^2 + R^2)^{3/2}} \times \frac{2R}{\mu_0 I} = \frac{R^3}{(r^2 + R^2)^{3/2}} = \frac{1}{8}$$

or $\dfrac{R}{(r^2 + R^2)^{1/2}} = \dfrac{1}{2} \Rightarrow r = \sqrt{3}R$

13. (a) : Here, $\dfrac{mv^2}{r} = qvB$

(as the uniform magnetic field is acting normal to the plane)

$\therefore$ $r = \dfrac{mv}{qB}$

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or $\frac{r_p}{r_\alpha} = \frac{m_p v}{qB} \times \frac{2qB}{m_\alpha v} = \frac{2m_p}{4m_p} = \frac{1}{2}$ $[\because m_\alpha = 4m_p]$

14. (c) : Charges crossing a point per second is current *i.e.*, $e \times \upsilon$ (this frequency of rotation is for a given radius).

$\therefore \quad I = 1.6 \times 10^{-19} \times 5 \times 10^{16} = 8 \times 10^{-3}$ A $= 8$ mA

The direction of the current is opposite to the motion of the electron *i.e.*, clockwise.

15. (c) : A charged particle while moving through the electric and magnetic fields can go undeflected if

(i) both $\vec{B}$ and $\vec{E}$ act along the direction of velocity or (ii) the force on charged particle due to electric field is equal and opposite to the force on it due to magnetic field. It will be so if both $\vec{B}$ and $\vec{E}$ are mutually perpendicular to each other and perpendicular to the direction of velocity.

Thus, option (c) is correct.

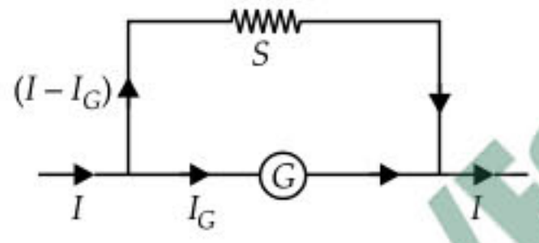
16. (d) : Both $\vec{v}$ and $\vec{B}$ are perpendicular to plane of parallel wires.

$\therefore \quad \vec{F} = q(\vec{v} \times \vec{B}) =$ zero

17. (b) : As shunt is a small resistance S in parallel with a galvanometer (of resistance G) as shown in figure.

$(I - I_G)S = I_G G$

$S = \frac{I_G G}{(I - I_G)}$



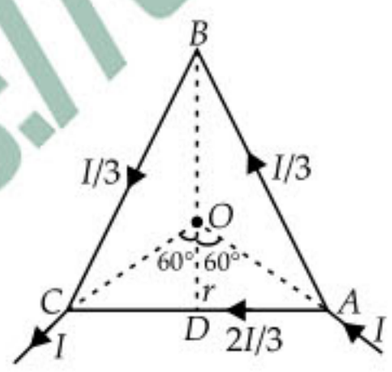
Here, $I_G = \frac{5}{100} I$

$\therefore \quad S = \frac{\frac{5}{100} IG}{I - \frac{5}{100} I} = \frac{G}{19}$

18. (d) : Let O is the centre of the equilateral triangle ABC.

Magnetic field at O due to current through AC is

$B_{AC} = \frac{\mu_0}{4\pi} \frac{(2I/3)}{r} [\sin 60° + \sin 60°] \otimes$



Magnetic field at O due to current through ABC is

$B_{ABC} = 2 \times \frac{\mu_0}{4\pi} \frac{(I/3)}{r} [\sin 60° + \sin 60°] \odot$

Resultant magnetic field at O is

$B = B_{ABC} \odot + B_{AC} \otimes$

$= 2 \times \frac{\mu_0}{4\pi} \frac{(I/3)}{r} [\sin 60° + \sin 60°] - \frac{\mu_0}{4\pi} \frac{(2I/3)}{r} [\sin 60° + \sin 60°]$

$B = 0$

19. (a) : Let r be the radius of the circular coil, then

$L = 2\pi \times r \times 2$ or $r = \frac{L}{4\pi}$

Area of the coil, $A = \pi r^2 = \pi \left(\frac{L}{4\pi}\right)^2$

$A = \pi \left(\frac{6.28 \times 6.28}{16 \times 3.14 \times 3.14}\right) = \frac{\pi}{4}$ m^2

Magnetic moment of the coil, $M = NIA$

$M = 2 \times 0.5$ A $\times \frac{\pi}{4}$ m$^2 = \frac{\pi}{4}$ A m^2

20. (a) : Potential energy, $U = -\vec{M} \cdot \vec{B} = -MB\cos\theta$,

where M is magnetic moment of the loop and θ is angle between $\vec{M}$ and $\vec{B}$.

When $\theta = 180°$, $U = -MB\cos 180° = +MB$

Potential energy is maximum.

When $\theta = 0°$,

$U = -MB\cos 0° = -MB$,

Potential energy is minimum.

$\therefore \quad$ As θ decreases from 180° to 0°, potential energy also decreases.

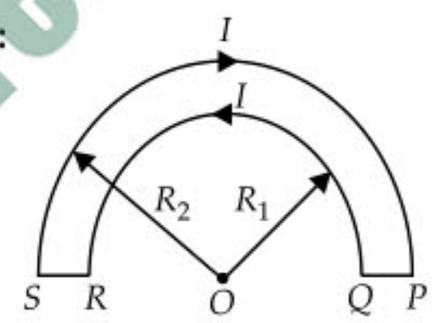
The decreasing order of potential energy will be I, IV, II, III.

21. (a) : Radius of the circular path of a charged particle in uniform magnetic field is $r = \frac{mv}{qB}$

For the same values of m, B

$r \propto \frac{v}{q} \quad \therefore \quad \frac{r_1}{r_2} = \frac{v_1}{v_2} \times \frac{q_2}{q_1} = \frac{2}{3} \times \frac{2}{1} = \frac{4}{3}$

22. (a) :



Magnetic induction at O due to semicircular arc QR of radius R_1 is

$B_{QR} = \frac{\mu_0 I\pi}{4\pi R_1} = \frac{\mu_0 I}{4R_1} \odot$

Magnetic induction at O due to straight portions PQ and RS is zero.

$\therefore \quad B_{PQ} = B_{RS} = 0$

(Since point O lying on the axis of the PQ and RS)

Magnetic induction at O due to semicircular arc SP of radius R_2 is

$B_{SP} = \frac{\mu_0 I\pi}{4\pi R_2} = \frac{\mu_0 I}{4R_2} \otimes$

Net magnetic field at O is

$B = B_{PQ} + B_{QR} + B_{RS} + B_{SP}$

$= 0 + \frac{\mu_0 I}{4R_1} + 0 - \frac{\mu_0 I}{4R_2} = \frac{\mu_0 I}{4}\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$

23. (b) : Here, $\vec{v} = x\hat{i} + y\hat{j}$

$\vec{B} = y\hat{i} + x\hat{j}$

Force on charged particle in a magnetic field is given by

$\vec{F} = q(\vec{v} \times \vec{B})$

$\vec{F} = q[(x\hat{i} + y\hat{j}) \times (y\hat{i} + x\hat{j})]$

$\vec{F} = q(x^2 - y^2)\hat{k}$

The magnitude of the force is

$F = q(x^2 - y^2)$

If $x = y$, $F = 0$

If $x > y$, $F \propto (x^2 - y^2)$

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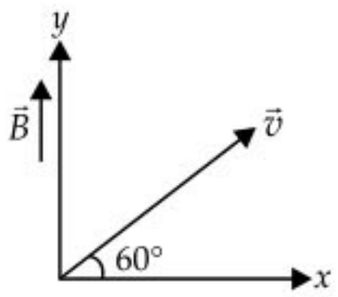
24. (c) : Since the proton is entering the magnetic field at some angle other than 90°, its path is helix. Component velocity of proton along x-axis,



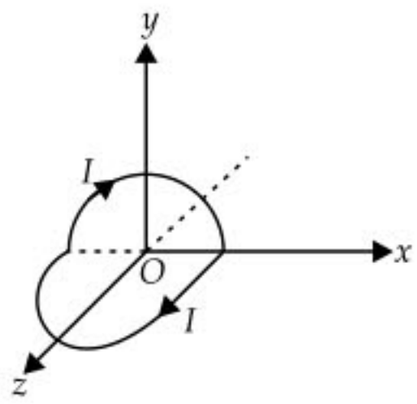
$$v_x = v\cos 60° = 2\times 10^6 \times \frac{1}{2} = 10^6 \text{ m s}^{-2}$$

Due to component velocity v_x, the radius of the helix described is given by the relation

$$r = \frac{mv_x}{qB} = \frac{1.67\times 10^{-27}\times 10^6}{1.6\times 10^{-19}\times 0.104} = 0.1 \text{ m}$$

Time period, $T = \frac{2\pi r}{v_x} = \frac{2\pi\times 0.1}{10^6} = 2\pi\times 10^{-7}$ s

25. (a) : The magnetic field at the centre O due to semicircular loop in x-y plane is



$$\vec{B}_{xy} = \frac{\mu_0}{4\pi}\frac{I}{R}\pi(-\hat{k}) = -\frac{\mu_0 I}{4R}\hat{k}$$

Magnetic field at the centre O due to current through semicircular loop in x-z plane is

$$\vec{B}_{xz} = \frac{\mu_0}{4\pi}\frac{I}{R}\pi(-\hat{j}) = -\frac{\mu_0 I}{4R}\hat{j}$$

Magnitude of resultant magnetic field at the centre O is

$$B = [B_{xy}^2 + B_{xz}^2]^{1/2} = \left[\left(\frac{\mu_0 I}{4R}\right)^2 + \left(\frac{\mu_0 I}{4R}\right)^2\right]^{1/2} = \frac{\mu_0 I}{4R}\sqrt{2} = \frac{\mu_0 I}{2\sqrt{2}R}$$

26. (c) : Magnetic moment, $M = IA$

$$M = \frac{qv}{2\pi r}\times \pi r^2 = \left(q\times\frac{\omega}{2\pi}\right)\pi r^2 = \frac{1}{2}q\omega r^2$$

Angular momentum,

$L = mvr = m(\omega r)r = m\omega r^2$

$$\therefore \quad \frac{M}{L} = \frac{\frac{1}{2}q\omega r^2}{m\omega r^2} = \frac{1}{2}\frac{q}{m}$$

27. (b) : Magnetic field at centre of the circular loop

$$B = \frac{\mu_0 NI}{2R}$$

Magnetic field due to an arc of a circle at the centre is

$$B = \left(\frac{\theta}{2\pi}\right)\frac{\mu_0 I}{2R} = \left(\frac{\mu_0}{4\pi}\right)\left(\frac{I}{R}\right)\theta$$

Here, $\theta = 30°$ and $I = 3$ A, $R = 0.6$ m

$$B = \left(\frac{\mu_0}{4\pi}\right)\left(\frac{3}{0.6}\right)\left(\frac{\pi}{6}\right) = \frac{10^{-7}\times 3\times\pi}{0.6\times 6} = 2.62\times 10^{-7} \text{ T}$$

28. (d) : Given : $\upsilon = 24\times 10^6$ Hz, $R = 0.60$ m

We know that, $R = \frac{mv}{qB}$ $\quad\therefore\quad$ $B = \frac{mv}{qR}$ ...(i)

where $v = \omega R = 2\pi\upsilon R$

$$v = 2\pi\times 24\times 10^6\times 0.60 = 9.04\times 10^7 \text{ m s}^{-1}$$

From (i)

$$B = \frac{(3.34\times 10^{-27})(9.04\times 10^7)}{1.6\times 10^{-19}\times 0.60} = 3.2 \text{ T}$$

29. (a) : Here, $I_g = \frac{1\times 150}{10} = 15 \text{ mA} = 15\times 10^{-3}$ A

$I_s = 10$ div/mA; $V_s = 2$ div/mV

$\therefore$ Resistance of galvanometer, $G = \frac{I_s}{V_s} = \frac{10}{2} = 5\ \Omega$

As galvanometer is to be converted into a voltmeter of range $1\times 150 = 150$ V, so resistance to be connected in series is

$$R = \frac{V}{I_g} - G = \frac{150}{15\times 10^{-3}} - 5 = 10000 - 5 = 9995\ \Omega$$

30. (c) : $\vec{F} = Q(\vec{v}\times\vec{B})$. Here $\vec{B}$ at P is perpendicular to the plane of current carrying wire directed inwards. Applying Fleming Left hand rule the direction $\vec{F}$ is along OY.

31. (a) : The magnetic field induction at a point on the axis at a distance d from the centre of the coil is given by

$$B = \frac{\mu_0}{4\pi}\frac{2\pi I a^2}{(a^2+d^2)^{3/2}}$$

where a = radius of the coil, I = current in the coil. The magnitude of the magnetic field due to current through both the loops will be the same but their directions will be perpendicular to each other. The resultant magnetic field at that point is

$$B_R = \sqrt{B^2+B^2} = \sqrt{2}B \qquad \therefore \quad \frac{B_R}{B} = \sqrt{2}$$

32. (a) : The magnetic field at point P due to currents through both the wires is

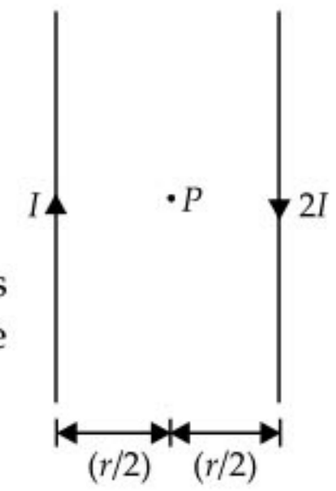
$$B = \frac{\mu_0}{4\pi}\frac{2I}{(r/2)} + \frac{\mu_0}{4\pi}\frac{2(2I)}{(r/2)}$$

$$= \frac{\mu_0}{4\pi}\times\frac{12I}{r}$$

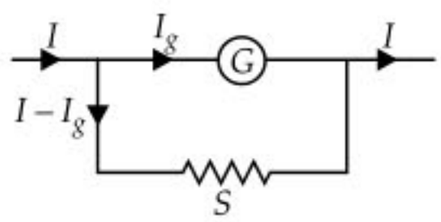
acting perpendicular to plane of wires inwards. Now $\vec{B}$ and $\vec{v}$ are acting in the same direction *i.e* $\theta = 0°$.

Force on charged particle is

$F = qvB\sin\theta = qvB\sin 0° =$ Zero



33. (b) :



Here, resistance of galvanometer, $G = 48\ \Omega$

$$I_g = \frac{4}{100}I = 0.04I$$

Let S be required shunt.

$$S = \frac{I_g G}{(I - I_g)} = \frac{0.04I\times 48}{(I - 0.04I)} = \frac{0.04\times 48}{0.96} = 2\ \Omega$$

34. (a) : Let L be the length of the wire. Then

$L = 2\pi r$

where r is the radius of the circular loop.

or $\quad r = \frac{L}{2\pi}$

Area of the loop, $A = \pi r^2 = \pi\left(\frac{L}{2\pi}\right)^2 = \frac{L^2}{4\pi}$

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Magnetic moment, $M = IA = \dfrac{IL^2}{4\pi}$

or $L = \sqrt{\dfrac{4\pi M}{I}}$

35. (b)

36. (b) : Work done in changing the orientation of a magnetic needle of magnetic moment M in a magnetic field B from position θ_1 to θ_2 is given by

$W = MB(\cos\theta_1 - \cos\theta_2)$

Here, $\theta_1 = 0°$, $\theta_2 = 60°$

$\therefore\ W = MB(\cos 0° - \cos 60°)$

$$= MB\left(1 - \frac{1}{2}\right) = \frac{MB}{2} \qquad ...(i)$$

The torque on the needle is $\vec{\tau} = \vec{M} \times \vec{B}$

In magnitude,

$$\tau = MB\sin\theta = MB\sin 60° = \frac{\sqrt{3}}{2}MB \qquad ...(ii)$$

Dividing (ii) by (i), we get

$$\frac{\tau}{W} = \sqrt{3}$$

$\tau = \sqrt{3}W = \sqrt{3} \times \sqrt{3}$ J $= 3$ J

37. (b) : Let R be radius of a circular loop and I be current flowing in the loop.

Area of the loop, $A = \pi R^2$

π m$^2 = \pi R^2$ or $R = 1$ m

Magnetic induction at the centre of the circular loop is

$$B = \frac{\mu_0 I}{2R} \text{ or } 0.1 = \frac{\mu_0 I}{2\times 1} \text{ or } I = \frac{0.2}{\mu_0}$$

Magnetic moment of the loop

$$M = IA = \frac{0.2}{\mu_0} \times \pi = \frac{0.2\pi}{\mu_0}$$

38. (c) : Here, $E = 2$ MeV $= 2 \times 1.6 \times 10^{-13}$ J

$B = 2.5$ T, $m = 1.6 \times 10^{-27}$ kg, $\theta = 90°$, $q = 1.6 \times 10^{-19}$ C

As, $E = \dfrac{1}{2}mv^2$ or $v = \sqrt{\dfrac{2E}{m}}$

Now $F = qvB\sin\theta$

$$= q \times \sqrt{\frac{2E}{m}} \times B \times \sin 90° = q \times \sqrt{\frac{2E}{m}} \times B$$

$$= (1.6 \times 10^{-19}) \times \sqrt{\frac{2\times 2\times 1.6\times 10^{-13}}{1.6\times 10^{-27}}} \times 2.5 = 8 \times 10^{-12} \text{ N}$$

39. (d) : As the two coils are concentric and in the same plane, carrying currents in opposite directions, the total magnetic field at the centre of the concentric coils is

$$B = B_1 - B_2 = \frac{\mu_0}{4\pi}\frac{2\pi N_1 I_1}{r_1} - \frac{\mu_0}{4\pi}\frac{2\pi N_2 I_2}{r_2}$$

$$= \frac{\mu_0}{2}\left[\frac{N_1 I_1}{r_1} - \frac{N_2 I_2}{r_2}\right] = \frac{\mu_0}{2}\left[\frac{10\times 0.2}{0.2} - \frac{10\times 0.3}{0.4}\right] = \frac{5}{4}\mu_0$$

40. (d) : Magnetic force acting on a charged particle of charge q moving with velocity $\vec{v}$ in a uniform magnetic field is

$\vec{F} = q(\vec{v} \times \vec{B})$

$$= -(2\times 10^{-6})\left[\left(2\hat{i} + 3\hat{j}\right)10^6 \times 2\hat{j}\right)\right]$$

$$= -(2\times 10^{-6})\left[4\hat{k}\right]10^6 = -8\hat{k} = 8 \text{ N in } -z \text{ direction}$$

41. (a) : Magnetic dipole moment of current loop is

$M = NIA = 10 \times 0.5 \times 2 \times 10^{-4} = 10^{-3}$ A m^2

Magnetic field inside the solenoid carrying current

$B = \mu_0 nI = 4\pi \times 10^{-7} \times 10^3 \times 3 = 12\pi \times 10^{-4}$ T

$\therefore$ Toque, $\tau = MB\sin\theta$

$= 10^{-3} \times 12\pi \times 10^{-4} \times \sin 90° = 12\pi \times 10^{-7}$ N m

42. (a) : Here, $n = 25$ turns, $r = 15$ cm $= 15 \times 10^{-2}$ m, $H = 3 \times 10^{-5}$ T, $\theta = 45°$ and $\mu_0 = 4\pi \times 10^{-7}$ N A^{-2}

$\therefore\quad B = \dfrac{\mu_0 nI}{2r} = H\tan\theta$

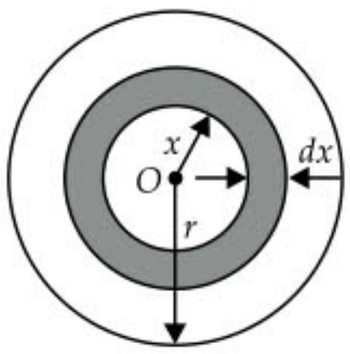
$\therefore\quad I = \dfrac{2rH\tan\theta}{\mu_0 n}$

$$= \frac{2\times 15\times 10^{-2}\times 3\times 10^{-5}\tan 45°}{(4\pi\times 10^{-7})\times 25} = 0{\cdot}29 \text{ A}$$

43. (b) : Here, $I_g = 0{\cdot}005$ A ; $V = 5$ V, $R = 975\ \Omega$

$\because\quad R = \dfrac{V}{I_g} - G$ or $G = \dfrac{V}{I_g} - R = \dfrac{5}{0{\cdot}005} - 975 = 25\ \Omega$

44. (b) : Consider a hypothetical ring of radius x and thickness dx of a disc as shown in figure.



Charge on the ring,

$$dq = \frac{q}{\pi r^2} \times (2\pi\, xdx)$$

Current due to rotation of charge on ring is

$$dI = \frac{dq}{T} = \frac{dq}{1/n} = ndq = \frac{nq(2x\,dx)}{r^2}$$

Magnetic field at the centre O due to current on ring element is

$$dB = \frac{\mu_0\, dI}{2x} = \frac{\mu_0\, nq(2xdx)}{r^2(2x)} = \frac{\mu_0\, nqdx}{r^2}$$

Total magnetic field induction due to current on whole disc is

$$B = \int_0^r \left(\frac{\mu_0\, nq}{r^2}\right) dx = \frac{\mu_0\, nq}{r^2}[x]_0^r = \frac{\mu_0\, nq}{r}$$

45. (d) : Magnetic field at the centre of circular loop,

$$B = \frac{\mu_0}{4\pi}\frac{2\pi I}{r} = \frac{\mu_0 I}{2r} \text{ or } I = \frac{2Br}{\mu_0}$$

Also, $A = \pi r^2$ or $r = \left(\dfrac{A}{\pi}\right)^{1/2}$

Magnetic moment, $M = IA = \dfrac{2Br}{\mu_0}A$

$$= \frac{2BA}{\mu_0} \times \left(\frac{A}{\pi}\right)^{1/2} = \frac{2BA^{3/2}}{\mu_0 \pi^{1/2}}$$

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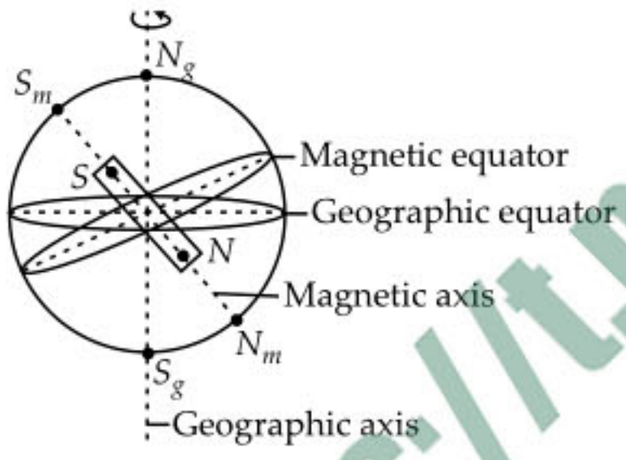
Magnetism and Matter

The Earth's Magnetism

A freely suspended magnet always points in the *N*-*S* direction even in the absence of any other magnet. This suggests that earth itself behaves as a magnet that holds the freely suspended magnet in a particular (*N*-*S*) direction. The studies show that shape of earth's magnetic field resembles that of a bar magnet of length one fifth of earth's diameter buried at its centre. The axis of earth's imaginary magnet is inclined roughly 11.3° west of the axis of rotation of earth, which is along geographic north N_g and geographic south S_g.



As north pole of a freely suspended magnet points approximately towards N_g, therefore, earth's magnetic pole near N_g is called south magnetic pole S_m. Similarly, the magnetic pole near S_g is called north magnetic pole N_m. The positions of earth's magnetic poles are not well defined on the globe. They are spread over some area. The strength of earth's magnetic field is of the order of 10^{-5} T.

The great circle perpendicular to earth's magnetic axis is called **magnetic equator**. The great circle perpendicular to geographic axis of earth is called **geographic equator.**

A vertical plane passing through magnetic axis is called magnetic meridian and a vertical plane passing through geographic axis is called geographic meridian.

Elements of the earth's magnetic field

Three quantities are needed to specify the magnetic field of the earth on its surface – the horizontal component, the magnetic declination and the magnetic dip. These are called as elements of the earth's magnetic field or magnetic elements.

Magnetic declination :

Magnetic declination at a place is defined as the angle between the geographic meridian and magnetic meridian.

Magnetic dip or magnetic inclination :

Magnetic dip at a place is defined as the angle made by the earth's magnetic field with the horizontal in the magnetic meridian. It is denoted by δ.

Horizontal component :

It is component of earth's magnetic field along the horizontal direction in the magnetic meridian. It is denoted by B_H.

If B is the earth's total magnetic field, then the horizontal component of earth's magnetic field is given by

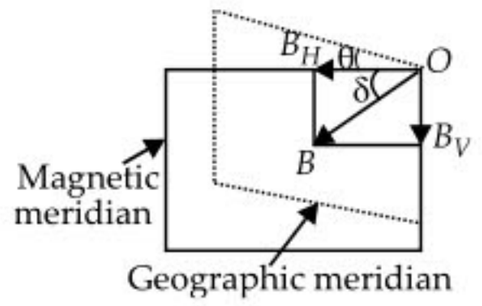
$$B_H = B\cos\delta$$

Also, the vertical component of earth's magnetic field,

$$B_V = B\sin\delta$$

$$\therefore \quad B = \sqrt{B_H^2 + B_V^2}$$

and $$\tan\delta = \frac{B_V}{B_H}$$



More about angle dip

At magnetic poles, δ = 90° and at magnetic equator, δ = 0°.

In a vertical plane at an angle θ to magnetic meridian

$$B'_H = B_H\cos\theta \text{ and } B'_V = B_V$$

$$\therefore \quad \tan\delta' = \frac{B'_V}{B'_H} = \frac{B_V}{B_H\cos\theta} = \frac{\tan\delta}{\cos\theta}$$

$$\tan\delta' = \frac{\tan\delta}{\cos\theta}$$

If δ_1 and δ_2 are observed angles of dip in two arbitrary vertical planes which are perpendicular to each other, then the true angle of dip δ is given by the relation

$$\cot^2\delta = \cot^2\delta_1 + \cot^2\delta_2$$

If λ is magnetic latitude at a place, then the angle of dip δ at the place is given by

$$\tan\delta = 2\tan\lambda$$

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Vibration Magnetometer

It is used for comparing magnetic moments of two magnets and also for comparing the horizontal component of earth's field at two places. It is based on the principle that bar magnet suspended freely in a uniform magnetic field is displaced from its equilibrium position, it starts executing simple harmonic motion about the equilibrium position. It is also used to determine horizontal component of earth's magnetic field.

If a bar magnet of magnetic dipole moment M and moment of inertia I is free to oscillate under the action of horizontal component of earth's magnetic field B_H, then its time period is given by

$$T = 2\pi\sqrt{\frac{I}{MB_H}}$$

Magnetic field at a point due to magnetic dipole (or bar magnet)

The magnetic field due to a bar magnet at any point on the axial line (end on position) is given by

$$B_{\text{axial}} = \frac{\mu_0}{4\pi}\frac{2Mr}{(r^2 - l^2)^2}$$

where r = distance between the centre of the magnet and the given point on the axial line, $2l$ = magnetic length of the magnet and M = magnetic moment of the magnet.

For short magnet, $l^2 << r^2$

$$B_{\text{axial}} = \frac{\mu_0 2M}{4\pi r^3}$$

The direction of B_{axial} is along SN.

The magnetic field due to a bar magnet at any point on the equatorial line (board-side on position) of the bar magnet is given by

$$B_{\text{equatorial}} = \frac{\mu_0 M}{4\pi(r^2 + l^2)^{3/2}}$$

For short magnet, $l^2 << r^2$

$$B_{\text{equatorial}} = \frac{\mu_0 M}{4\pi r^3}$$

The direction of $B_{\text{equatorial}}$ is parallel to NS.

Work done in rotating the magnetic dipole in a uniform magnetic field

Work done in rotating the magnetic dipole from θ_1 to θ_2 with respect to uniform magnetic field is

$$W = \int_{\theta_1}^{\theta_2} MB\sin\theta\, d\theta = -MB(\cos\theta_2 - \cos\theta_1) = MB(\cos\theta_1 - \cos\theta_2)$$

If the dipole is rotated from field direction *i.e.* $\theta_1 = 0°$ to position θ *i.e.* $\theta_2 = \theta$

$\therefore \quad W = MB(1 - \cos\theta)$.

Potential energy of a magnetic dipole in a uniform magnetic field

Potential energy of a magnetic dipole in a uniform magnetic field is

$$U = -\vec{M}\cdot\vec{B} = -MB\cos\theta$$

Potential energy is minimum $(= -MB)$ at $\theta = 0°$, which is the most stable position and maximum $(= +MB)$ at $\theta = 180°$, which is the most unstable position.

Classification of Magnetic Materials

On the basis of magnetic properties, different materials have been classified into three categories :

- Diamagnetic substances
- Paramagnetic substances
- Ferromagnetic substances

Diamagnetic substances :

Diamagnetic substances are those substances which get feebly magnetised in a direction opposite to the field when placed in an external magnetic field. They have tendency to move from stronger to the weaker part of the external magnetic field. *i.e.* they get weakly repelled to a magnet. The individual atoms (or ions or molecules) of a diamagnetic substance do not possess a permanent dipole moment of their own. Some diamagnetic materials are bismuth, copper, lead, silicon, nitrogen (at STP), water and sodium chloride. Dimagnetism is present in all the substances. However, the effect is so weak in most cases that it gets shifted by other effects like paramagnetism, ferromagnetism, etc. The most exotic diamagnetic materials are **superconductors.**

The relative permeability of diamagnetic substances is less than one. The magnetic susceptibility of diamagnetic substances is small and negative. The magnetic susceptibility of diamagnetic substances is independent of temperature.

Paramagnetic substances :

Paramagnetic substances are those substances which get weekly magnetised in direction of the external magnetic field when placed in an external magnetic field. They have tendency to move from a region of weak magnetic field to strong magnetic field *i.e.* they get weakly attracted to a magnet. The individual atoms (or ions or molecules) of a paramagnetic material possess a permanent magnetic dipole moment of their own. Some paramagnetic substances are aluminium, sodium, calcium, oxygen (at STP) etc. Paramagnetic substances on being subjected to a non-uniform magnetic field tend to move from the weaker to the stronger parts of the field.

The relative permeability of paramagnetic substances is just greater than one. The magnetic susceptibility of paramagnetic substances is small and positive. The magnetic susceptibility of paramagnetic substance is dependent on the temperature and it varies inversely with absolute temperature according to the given equation

$$\chi_m = \frac{C}{T}$$

This is known as **Curie law.** The constant C is known as Curie's constant.

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Ferromagnetic substances :

Ferromagnetic substances are those substances which get strongly magnetised in the direction of external magnetic field when placed in an external magnetic field. They have strong tendency to move from a region of weak magnetic field to strong magnetic field *i.e.* they get strongly attracted to a magnet. The individual atoms (or ions or molecules) in a ferromagnetic substance possess a dipole moment as in a paramagnetic substance. However, they interact with one another in such a way that they spontaneously align themselves in a common direction over a macroscopic volume called domain. Each domain has net magnetisation. Typical domain size is 1 mm and the domain contains about 10^{11} atoms. Some ferromagnetic substances are iron, cobalt, nickel, gadolinium, alnico etc. Ferromagnetic substance on being subjected to a non-uniform magnetic field tend to move from the weaker to the stronger parts of the field.

The relative magnetic permeability of ferromagnetic substances is very large. The magnetic susceptibility of ferromagnetic substance is positive and very large. The ferromagnetic property depends on temperature. At high temperature, ferromagnetic becomes paramagnetic. The temperature of transition from ferromagnetic to paramagnetic is known as Curie temperature (T_C). The susceptibility above the Curie temperature *i.e.* in the paramagnetic phase is given by

$$\chi_m = \frac{C}{T - T_C} (T > T_C)$$

This is known as **Curie Weiss law.**

Hysteresis

Hysteresis is the phenomenon of lagging of magnetic induction (B) or intensity of magnetisation (I) behind the magnetising field (H), when a specimen is taken through a cycle of magnetisation. From the hysteresis loop of material, we can study about retentivity, coercivity etc. of the material. The loss of energy per unit volume of the specimen per cycle of magnetisation is equal to area of the I-H loop or $1/4\pi$ time the area of B-H loop of the specimen. The study of these characteristics enables us to select suitable materials for different purposes.

On the basis of retentivity, coercivity and hystersis loss, ferromagnetic materials are divided into two types :

Soft magnetic materials :

These have low retentivity, low coercivity and small hysteresis loss. These are used for making electromagnets, cores or transformers, motors and generators. Soft iron, mu-metal and stalloy are examples of these materials

Hard magnetic materials :

These have high retentivity, high coercivity and large hysteresis loss. These are used in making permanent magnets of various kinds of electric meters and loudspeakers. Steel, alnico, alcomax and ticonal are examples of ferromagnetic materials of these materials.

Permanent Magnets

Substances which at room temperature retain their ferromagnetic property for a long period of time are called permanent magnets.

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EXAM DRILL

1. Choose the correct statement.
(a) A paramagnetic material tends to move from a strong magnetic field to weak magnetic field.
(b) A magnetic material is in the paramagnetic phase below its Curie temperature.
(c) The resultant magnetic moment in an atom of a diamagnetic substance is zero.
(d) Typical domain size of a ferromagnetic material is 1 nm.

2. A magnet makes 5 oscillations per minute in $B = 0.3 \times 10^{-4}$ T. By what amount should the field be increased so that number of oscillations is 10 in the same time?
(a) 0.3×10^{-4} T (b) 0.6×10^{-4} T
(c) 0.9×10^{-4} T (d) 1.2×10^{-4} T

3. A magnetising field of 1600 A m^{-1} produces a magnetic flux of 2.4×10^{-5} Wb in an iron bar of cross-sectional area 0.2 cm^2. The susceptibility of an iron bar is
(a) 298 (b) 596
(c) 1192 (d) 1788

4. Among which, the magnetic susceptibility does not depend on the temperature?
(a) Diamagnetism
(b) Paramagnetism
(c) Ferromagnetism
(d) Ferrite

5. A magnet takes a minute to make 30 oscillations in a magnetic field. If the field strength is doubled, then the time period of oscillation (in s) is
(a) $\sqrt{2}$ (b) $2\sqrt{2}$
(c) $\frac{\sqrt{3}}{2}$ (d) $\sqrt{3}$

6. The ferromagnetic core of electromagnets should have
(a) a broad hysteresis loop
(b) high permeability and high retentivity
(c) low permeability and low retentivity
(d) high permeability and low retentivity

7. In a certain place, the vertical component of earth's magnetic field is 0.5 oersted and dip angle is 60°. The earth's magnetic field at that place is
(a) 1 oersted (b) $\frac{\sqrt{3}}{2}$ oersted
(c) 2 oersted (d) $\frac{1}{\sqrt{3}}$ oersted

8. A short bar magnet of magnetic moment 0.4 J T^{-1} is placed in a uniform magnetic field of 0.16 T. The magnet is in stable equilibrium when the potential energy is
(a) –0.064 J (b) zero
(c) –0.082 J (d) 0.064 J

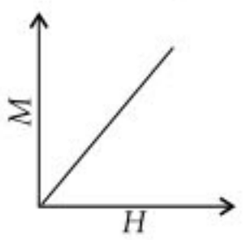
9. The effect due to uniform magnetic field on a freely suspended magnetic needle is as follows
(a) both torque and net force are present
(b) torque is present but no net force
(c) both torque and net force are absent
(d) net force is present but not torque

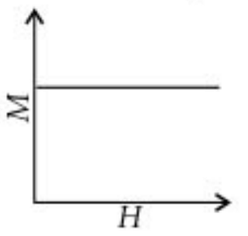
10. A magnetic needle has magnetic moment 5.8×10^{-2} A m^2 and moment of inertia of 7.8×10^{-6} kg m^2, it performs 12 complete oscillations in 6.0 s. What is the magnitude of magnetic field?
(a) 0.011 T (b) 0.021 T
(c) 0.031 T (d) 0.041 T

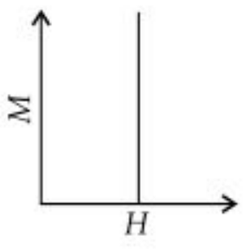
11. The torque and magnetic potential energy of a magnetic dipole in most stable position in a uniform magnetic field $(\vec{B})$ having magnetic moment $(\vec{m})$ will be
(a) $-mB$, zero (b) mB, zero
(c) zero, mB (d) zero, $-mB$.

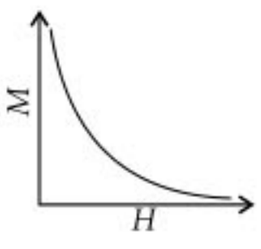
12. What is the magnitude of axial field due to a bar magnet of length 3 cm at a distance of 75 cm from its mid-point if its magnetic moment is 0.6 A m^2?
(a) 0.013 μT (b) 0.113 μT
(c) 0.284 μT (d) 0.313 μT

13. The correct M-H curve for a paramagnetic material at a constant temperature (T) is represented by

(a) 

(b) 

(c) 

(d) 

14. Superconductors are
(a) most exotic diamagnetic materials
(b) ferromagnetic material with low resistivity
(c) paramagnetic materials at high temperature
(d) none of these

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15. If a magnetic material is having magnetic susceptibility (χ) = –1, then the relative magnetic permeability (μ_r) and type of magnetic material are respectively
(a) 0, diamagnetic (b) 2, ferromagnetic
(c) 1, paramagnetic (d) –1, diamagnetic

16. Two identical magnetic dipoles of magnetic moment 2 A m^2 are placed at a separation of 2 m with their axes perpendicular to each other in air. The resultant magnetic field at a midpoint between the dipoles is
(a) $4\sqrt{5} \times 10^{-5}$ T (b) $2\sqrt{5} \times 10^{-5}$ T
(c) $4\sqrt{5} \times 10^{-7}$ T (d) $2\sqrt{5} \times 10^{-7}$ T

17. A short bar magnet has a magnetic moment of 0.48 J T^{-1}. The magnitude and direction of magnetic field produced by the magnet at a distance of 10 cm from the centre of the magnet on its axis is
(a) 0.48×10^{-4} along N-S direction
(b) 0.28×10^{-4} T along S-N direction
(c) 0.28×10^{-4} T along N-S direction
(d) 0.96×10^{-4} T along S-N direction

18. A short bar magnet has a magnetic moment of 0.39 J T^{-1}. The magnitude and direction of the magnetic field produced by the magnet at a distance of 20 cm from the centre of the magnet on the equatorial line of the magnet is
(a) 0.049 G, N-S direction
(b) 4.95 G, S-N direction
(c) 0.0195 G, S-N direction
(d) 19.5 G, N-S direction

19. At a certain location in Africa, compass points 12° west of geographic north. The north tip of magnetic needle of a dip circle placed in the plane of magnetic meridian points 60° above the horizontal. The horizontal component of earth's field is measured to be 0.16 G. The magnitude of earth's field at the location is
(a) 0.32 G (b) 0.42 G
(c) 4.2 G (d) 3.2 G

20. The magnetic induction at a point 1 Å away from a proton measured along its axis of spin is
(Take magnetic moment of the proton as 1.4×10^{-26} A m^2).
(a) 0.28 mT (b) 28 mT
(c) 0.028 mT (d) 2.8 mT

21. A permanent magnet in the shape of a thin cylinder of length 50 cm has intensity of magnetisaton 10^6 A m^{-1}. The magnetisation current is
(a) 5×10^5 A (b) 6×10^5 A
(c) 5×10^4 A (d) 6×10^4 A

22. A domain in ferromagnetic iron is in the form of a cube of side length 2 μm then the number of iron atoms in the domain are (Molecular mass of iron = 55 g mol^{-1} and density = 7.92 g cm^{-3})
(a) 6.92×10^{12} atoms
(b) 6.92×10^{11} atoms
(c) 6.92×10^{10} atoms
(d) 6.92×10^{13} atoms

23. The magnetic susceptibility of a paramagnetic material at – 73°C is 0.0075, its value at – 173°C will be
(a) 0.0045 (b) 0.0030
(c) 0.0150 (d) 0.0075

24. Point out the correct set of diamagnetic substances
(a) aluminium, sodium, calcium and oxygen
(b) bismuth, copper, lead and silicon
(c) cobalt, nickel, gadolinium and aluminium
(d) silver, niobium, magnesium and calcium

25. A domain in ferromagnetic iron in the form of cube is having 5×10^{10} atoms. If the side length of this domain is 1.5 μm and each atom has a dipole moment of 8×10^{-24} A m^2, then magnetisation of domain is
(a) 11.8×10^5 A m^{-1} (b) 1.18×10^4 A m^{-1}
(c) 11.8×10^4 A m^{-1} (d) 1.18×10^5 A m^{-1}

26. The magnetic field of Earth can be modelled by that of a point dipole placed at the centre of the Earth. The dipole axis makes an angle of 11.3° with the axis of Earth. At Mumbai, declination is nearly zero. Then,
(a) the declination varies between 11.3° W to 11.3° E.
(b) the least declination is 0°.
(c) the plane defined by dipole axis and Earth axis passes through Greenwich.
(d) declination averaged over Earth must be always negative.

27. A magnetising field of 1500 A m^{-1} produces flux of 2.4×10^{-5} weber in an iron bar of the cross-sectional area of 0.5 cm^2. The permeability of the iron bar is
(a) 245 (b) 250
(c) 252 (d) 255

28. A long solenoid has 1000 turns per metre and carries a current of 1 A. It has a soft iron core of $\mu_r = 1000$. The core is heated beyond the Curie temperature T_c.
(a) The $\vec{H}$ field in the solenoid is (nearly) unchanged but $\vec{B}$ field decreases drastically.
(b) The $\vec{H}$ and $\vec{B}$ fields in the solenoid are nearly unchanged.
(c) The magnetisation in the core reverses direction.
(d) The $\vec{H}$ field in the solenoid decreases but $\vec{B}$ field increases drastically.

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29. Assume the dipole model for earth's magnetic field B which is given by the vertical component of magnetic field, $B_V = \frac{\mu_0}{4\pi}\frac{2m\cos\theta}{r^3}$ and the horizontal component of magnetic field $B_H = \frac{\mu_0}{4\pi}\frac{m\sin\theta}{r^3}$, where $\theta = 90°$ (latitude as measured from magnetic equator), then the loci of point for which dip angle is $\pm 45°$.
(a) $\tan^{-1}(3)$ (b) $\tan^{-1}(2)$
(c) $\tan^{-1}(0.5)$ (d) $\tan^{-1}(1)$

30. At a given place on earth's surface the horizontal component of earths magnetic field is 2×10^{-5} T and resultant magnetic field is 4×10^{-5} T. The angle of dip at this place is
(a) 30° (b) 60°
(c) 90° (d) 45°

31. The earth behaves as a magnet with magnetic field pointing approximately from the geographic
(a) North to South
(b) South to North
(c) East to West
(d) West to East

32. The strength of the earth's magnetic field is
(a) constant everywhere
(b) zero everywhere
(c) having very high value
(d) vary from place to place on the earth's surface

33. The equatorial magnetic field of earth is 0.4 G. Then its dipole moment on equator is
(a) 1.05×10^{23} A m^2 (b) 2.05×10^{23} A m^2
(c) 1.05×10^{21} A m^2 (d) 2.05×10^{21} A m^2

34. In the magnetic meridian of a certain place the horizontal component of earth's magnetic field is 0.25 G and dip angle is 60°. The magnetic field of the earth at this location is
(a) 0.50 G (b) 0.52 G
(c) 0.54 G (d) 0.56 G

35. The dip angle at a location in southern India is about 18°. Then the dip angle in Britain will be
(a) greater than 18°
(b) lesser than 18°
(c) equal to 18°
(d) zero

36. Let the magnetic field on earth be modelled by that of a point magnetic dipole at the centre of earth. The angle of dip at a point on the geographical equator is
(a) always zero
(b) positive, negative or zero
(c) unbounded
(d) always negative

37. Consider the plane S formed by the dipole axis and the axis of earth. If P be the point of intersection of the geographical and magnetic equators then the declination and dip angle at point P are
(a) 0°, 11.3° (b) 11.3°, 0°
(c) 11.3°, 11.3° (d) 0°, 0°

38. If you made a map of magnetic field lines at melbourne in Australia, then the magnetic field lines seem to be
(a) go into the ground
(b) come out of the ground
(c) maintain a spiral path on the surface of earth
(d) move on helical path above the surface of ground

39. Which of the following is not correct about relative magnetic permeability (μ_r)?
(a) It is a dimensionless pure ratio.
(b) For vacuum medium its value is one.
(c) For ferromagnetic materials $\mu_r >> 1$
(d) For paramagnetic materials $\mu_r > 1$.

40. Out of given paramagnetic substance (Calcium, Chromium, Oxygen and Tungsten) which substance has maximum susceptibility?
(a) Calcium (b) Chromium
(c) Oxygen (d) Tungsten

41. Magnetic susceptibility of a diamagnetic substances
(a) increases with increase in temperature
(b) increases with decrease in temperature
(c) remains constant with change in temperature
(d) none of these

42. Which of following property shows the property of ferromagnetic substances?
(a) The ferromagnetic property depends on temperature.
(b) The ferromagnetic property does not depend on temperature.
(c) At high enough temperature ferromagnet becomes a diamagnet.
(d) At low temperature ferromagnet becomes a paramagnet.

43. The temperature of transition from ferromagnetic property to paramagnetic property is called
(a) Transition temperature
(b) Critical temperature
(c) Curie temperature
(d) Triplet temperature.

44. The magnetising field required to be applied in opposite direction to reduce residual magnetism to zero is called
(a) retentivity (b) coercivity
(c) hysteresis (d) flux

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45. Permanent magnets are the substances having the property of
(a) ferromagnetism at room temperature for a long period of time.
(b) paramagnetism at room temperature for a long period of time.
(c) anti ferromagnetism at room temperature for a long period of time.
(d) diamagnetism at room temperature for a long period of time.

DAY 19 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____
(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (c) : Diamagnetic substances are those substances in which resultant magnetic moment in an atom is zero.
A paramagnetic material tends to move from a weak magnetic field to strong magnetic field.
A magnetic material is in the paramagnetic phase above its Curie temperature.
Typical domain size of a ferromagnetic material is 1 mm.

2. (c) : $\upsilon = \frac{1}{2\pi}\sqrt{\frac{MB}{I}}$

$\therefore \quad \upsilon^2 \propto B$

$\frac{B_2}{B_1} = \frac{\upsilon_2^2}{\upsilon_1^2} = \frac{10^2}{5^2} = 4$

$B_2 = 4B_1 = 4 \times 0.3 \times 10^{-4}\ \text{T} = 1.2 \times 10^{-4}\ \text{T}$
Increase in field $= B_2 - B_1 = 0.9 \times 10^{-4}\ \text{T}$

3. (b): Here, $H = 1600\ \text{A m}^{-1}$,
Magnetic flux $(\phi) = 2.4 \times 10^{-5}\ \text{Wb}$
$A = 0.2\ \text{cm}^2 = 0.2 \times 10^{-4}\ \text{m}^2$

$\therefore \quad B = \frac{\phi}{A} = \frac{2.4 \times 10^{-5}}{0.2 \times 10^{-4}} = 1.2\ \text{Wb m}^{-2}$

$\therefore \quad \mu = \frac{B}{H} = \frac{1.2}{1600} = 7.5 \times 10^{-4}\ \text{N A}^{-2}$

Hence, susceptibility $\chi = \frac{\mu}{\mu_0} - 1 = \frac{7.5 \times 10^{-4}}{4\pi \times 10^{-7}} - 1 = 596$

4. (a) : In diamagnetism, susceptibility does not depend on temperature.

5. (a) : The time period of oscillation is

$T = 2\pi\sqrt{\frac{I}{MB}}$

where I is the moment of inertia, M is the magnetic moment and B is the magnetic field.
Since, I and M remain the same,

$T \propto \frac{1}{\sqrt{B}}$

$\therefore \quad \frac{T'}{T} = \sqrt{\frac{B}{B'}} = \sqrt{\frac{B}{2B}} = \frac{1}{\sqrt{2}}$

$T' = \frac{T}{\sqrt{2}} = \frac{1}{\sqrt{2}}\left(\frac{60}{30}\ \text{s}\right) = \frac{2}{\sqrt{2}}\ \text{s} = \sqrt{2}\ \text{s}$

6. (d): The ferromagnetic core of electromagnets should have high permeability and low retentivity.

7. (d): Here,
Vertical component of earth's magnetic field,
$V_E = 0.5$ oersted
Angle of dip, $\delta = 60°$
Earth's magnetic field, $B_E = ?$

As $\sin\delta = \frac{V_E}{B_E}$

$\therefore \quad B_E = \frac{V_E}{\sin\delta} = \frac{0.5}{\sin 60°} = \frac{0.5}{\left(\frac{\sqrt{3}}{2}\right)} = \frac{1}{\sqrt{3}}$ oersted

8. (a) : Here, $M = 0.4\ \text{J T}^{-1}$; $B = 0.16\ \text{T}$
For stable equilibrium, the potential energy (U) of bar magnet in the magnetic field is
$U = -MB = -0.4 \times 0.16 = -0.064\ \text{J}$

9. (b): When a freely suspended magnetic needle is placed in a uniform magnetic field, it experiences torque but no net force.

10. (b): Here, time period of oscillations

$T = \frac{6.0}{12} = 0.5\ \text{s}$

Now, magnetic field, $B = \frac{4\pi^2 I}{mT^2}$

Here, $I = 7.8 \times 10^{-6}\ \text{kg m}^2$,
$m = 5.8 \times 10^{-2}\ \text{A m}^2$

$\therefore \quad B = \frac{4 \times (3.14)^2 \times 7.8 \times 10^{-6}}{5.8 \times 10^{-2} \times (0.5)^2} = 0.021\ \text{T}$

11. (d): Torque, $\vec{\tau} = \vec{m} \times \vec{B} = mB\sin\theta$
and magnetic potential energy
$U_m = -\vec{m}.\vec{B} = -mB\cos\theta$
At $\theta = 0°$ the dipole will be in most stable position
$\tau = mB\sin\theta = mB\sin 0 = 0$
and $U_m = -mB\cos\theta = -mB\cos 0 = -mB$

12. (c) : Here, $m = 0.6\ \text{A m}^2$, $r = 75\ \text{cm} = 0.75\ \text{m}$

$B_{\text{axial}} = \frac{\mu_0}{4\pi} \cdot \left(\frac{2m}{r^3}\right) = 10^{-7} \times \frac{2 \times 0.6}{(0.75)^3}$

$\therefore \quad B_{\text{axial}} = 2.84 \times 10^{-7}\ \text{T} = 0.284\ \mu\text{T}.$

13. (a) : Since intensity of magnetisation (M) of a paramagnetic material is given by

$M = C\frac{B}{T} = C\mu_0\frac{H}{T}$ as $\frac{C\mu_0}{T}$ is constant.

Then, $M \propto H$
Hence, the M_H curve will be a straight line with the slope $C\mu_0\frac{H}{T}$.

14. (a) : Superconductors are most exotic diamagnetic materials. When these materials cooled to very low temperatures, which exhibits both perfect conductivity and perfect diamagnetism.

15. (a) : Here, $\chi = -1$
then $\mu_r = 1 + \chi$
$\mu_r = 1 + (-1) = 1 - 1 = 0$
Since, magnetic susceptibility of given material is less than one. Hence, the given magnetic material is a diamagnetic material.

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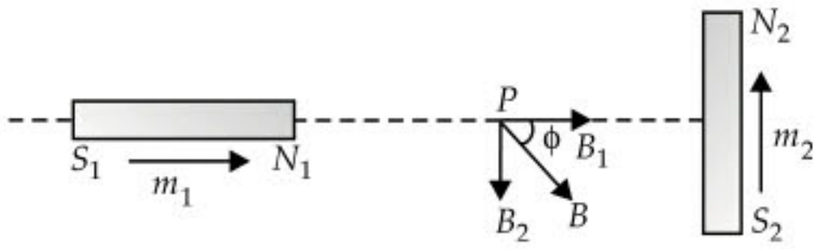
16. (d):



Let point P be a midpoint between the dipoles. The point P will be in end-on position with respect to one dipole and in broad-side position with respect to the other.

$$\therefore \quad B_1 = \frac{\mu_0}{4\pi}\frac{2m_1}{r_1^3} = \frac{10^{-7}\times 2\times 2}{(1)^3} = 4\times 10^{-7}\ \text{T}$$

$$\text{and} \quad B_2 = \frac{\mu_0}{4\pi}\frac{m_2}{r_2^3} = \frac{10^{-7}\times 2}{(1)^3} = 2\times 10^{-7}\ \text{T}$$

As B_1 and B_2 are perpendicular to each other, therefore the resultant magnetic field at point P is

$$B = \sqrt{B_1^2 + B_2^2} = \sqrt{(4\times 10^{-7})^2 + (2\times 10^{-7})^2}$$

$$= 10^{-7}\sqrt{16+4} = 10^{-7}\sqrt{20} = 2\sqrt{5}\times 10^{-7}\ \text{T}$$

17. (d): On the axis of the magnet

$$B = \frac{\mu_0}{4\pi}\cdot\frac{2m}{d^3}$$

Here, $\frac{\mu_0}{4\pi} = 10^{-7}\ \text{A m}^{-2}$, $m = 0.48\ \text{J T}^{-1}$,

$d = 10\ \text{cm} = 0.1\ \text{m} \quad \therefore \quad B = \dfrac{10^{-7}\times 2\times 0.48}{(0.1)^3}$

$= 0.96 \times 10^{-4}\ \text{T}$, along S-N direction.

18. (a): Here, $m = 0.39\ \text{J T}^{-1}$, $d = 20\ \text{cm} = 0.2\ \text{m}$

On the equatorial line of magnet

$$B = \frac{\mu_0}{4\pi}\cdot\frac{m}{d^3}$$

$$= 10^{-7}\times\frac{0.39}{(0.2)^3} = \frac{0.39\times 10^{-7}}{2^3\times 10^{-3}}$$

$= 0.049 \times 10^{-4}\ \text{T} = 0.049\ \text{G}$ along N-S direction

19. (a): Here, $H_E = 0.16\ \text{G} = 0.16\times 10^{-4}\ \text{T}$.

dip angle, $\delta = 60°$

Then, magnitude of earth's field.

$$B_E = \frac{H_E}{\cos\delta} = \frac{0.16\times 10^{-4}}{\cos 60°}, \quad B_E = \frac{0.16\times 10^{-4}}{1/2}$$

$= 0.32 \times 10^{-4}\ \text{T} = 0.32\ \text{G}$

20. (d): On the axis of a magnetic dipole magnetic induction is

$$B = \frac{\mu_0}{4\pi}\times\frac{2m}{r^3}$$

Here, $r = 1\ \text{Å} = 10^{-10}\ \text{m}$, $m = 1.4\times 10^{-26}\ \text{A m}^{-2}$ and

$$\frac{\mu_0}{4\pi} = 10^{-7}\ \text{N A}^{-2}$$

$$B = \frac{10^{-7}\times 2\times 1.4\times 10^{-26}}{(10^{-10})^3}$$

$$= \frac{10^{-7}\times 2.8\times 10^{-26}}{10^{-30}} = 2.8\times 10^{-3}\ \text{T} = 2.8\ \text{mT}$$

21. (a): Here, $l = 50\ \text{cm} = 0.5\ \text{m}$, $M = 10^6\ \text{A m}^{-1}$

$$\text{As} \quad M = \frac{\text{magnetisation current } (I_M)}{(\text{length})l}$$

$$\therefore \quad I_M = M\times l = 10^6\times 0.5 = 5\times 10^5\ \text{A}.$$

22. (b): The volume of the cubic domain

$V = (2\ \mu\text{m})^3 = (2\times 10^{-6}\ \text{m})^3 = 8\times 10^{-18}\ \text{m}^3 = 8\times 10^{-12}\ \text{cm}^3$

Also mass = volume × density

$= 8\times 10^{-12}\ \text{cm}^3 \times 7.9\ \text{g cm}^{-3} = 63.2\times 10^{-12}\ \text{g}$

Now the Avogadro number (6.023×10^{23}) of iron atoms have a mass of 55 g.

Hence the number of atoms in the domain are

$$N = \frac{63.2\times 10^{-12}\times 6.023\times 10^{23}}{55} = 6.92\times 10^{11}\ \text{atoms}$$

23. (c): Here, $\chi_{m1} = 0.0075$,

$T_1 = -73°\text{C} = (-73 + 273)\ \text{K} = 200\ \text{K}$

$\chi_{m_2} = ?$, $T_2 = -173°\text{C} = (-173 + 273)\ \text{K} = 100\ \text{K}$

For paramagnetic material magnetic susceptibility

$$\chi_m \propto \frac{1}{T} \Rightarrow \frac{\chi_{m_2}}{\chi_{m_1}} = \frac{T_1}{T_2} = \frac{200}{100} = 2$$

$$\therefore \quad \chi_{m_2} = 2\chi_{m_1} = 2\times 0.0075 = 0.015$$

24. (b): Bismuth, copper, lead and silicon all are having the property of diamagnetic as in the atoms of these material have resultant magnetic moment zero.

25. (d): The volume of the cubic domain is

$V = (1.5\times 10^{-6}\ \text{m})^3 = 3.38\times 10^{-18}\ \text{m}^3$

$= 3.38\times 10^{-12}\ \text{cm}^3$

Number of atoms in domain

$N = 5\times 10^{10}$ atoms

Since each iron atom has a dipole moment,

$m = 8\times 10^{-24}\ \text{A m}^2$

$m_{\max}$ = net dipole moment for all atoms

$= N\times m$

$= 5\times 10^{10}\times 8\times 10^{-24}$

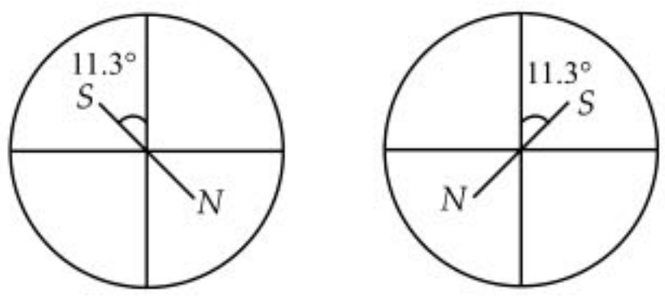
$= 40\times 10^{-14} = 4\times 10^{-13}\ \text{A m}^2$.

Now the consequent magnetisation

$$M_{\max} = \frac{m_{\max}}{\text{Domain volume}}$$

$$= \frac{4\times 10^{-13}\ \text{A m}^2}{3.38\times 10^{-18}\ \text{m}^3} = 1.18\times 10^5\ \text{A m}^{-1}$$

26. (a):



Since the axis of the magnetic dipole placed at the centre of earth makes an angle of 11.3° with the axis of earth, the two possibilities arise as shown in above figure. Hence, the declination varies between 11.3° W to 11.3° E.

27. (d): Here, $H = 1500\ \text{A m}^{-1}$, $\phi = 2.4\times 10^{-5}$ weber

$A = 0.5\ \text{cm}^2 = 0.5\times 10^{-4}\ \text{m}^2$

$$\therefore \quad B = \frac{\phi}{A} = \frac{2.4\times 10^{-5}}{0.5\times 10^{-4}} = 4.8\times 10^{-1}\ \text{T}$$

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and $\mu = \frac{B}{H} = \frac{4.8 \times 10^{-1}}{1500} = 3.2 \times 10^{-4}$ T m A^{-1}

So relative permeability

$$\mu_r = \frac{\mu}{\mu_0} = \frac{3.2 \times 10^{-4}}{4\pi \times 10^{-7}} = 0.255 \times 10^3 = 255$$

28. (a) : In solenoid, H field,

$H = nI$ and B field,

$B = \mu_0 \mu_r nI$

Now the core is heated beyond the Curie temperature T_c, due to that μ_r decrease and hence B will also decrease.

29. (b): Here, $B_V = \frac{\mu_0}{4\pi}\frac{2m\cos\theta}{r^3}$

$B_H = \frac{\mu_0}{4\pi}\frac{m\sin\theta}{r^3}$

and $\delta = 45° \quad \because \quad \tan\delta = \frac{B_V}{B_H}$

$\therefore \quad \tan 45° = \frac{2\cos\theta}{\sin\theta} = 2\cot\theta$

or $\quad 1 = \frac{2}{\tan\theta} \Rightarrow \tan\theta = 2$

or $\quad \theta = \tan^{-1}(2)$ is the loci of points.

30. (b): Since $B_H = B\cos\delta$

Here, $B = 4 \times 10^{-5}$ T, $B_H = 2 \times 10^{-5}$ T

$\therefore \quad \cos\delta = \frac{B_H}{B} = \frac{2 \times 10^{-5}}{4 \times 10^{-5}} = \frac{1}{2} = \cos 60°$

$\Rightarrow \quad \delta = 60°$

31. (b)

32. (d): The strength of the earths magnetic field is not constant. It varies from one place to other place on the surface of earth. Its value being of the order of 10^{-5} T.

33. (a) : Here, $B_E = 0.4$ G $= 0.4 \times 10^{-4}$ T

$r = 6.4 \times 10^6$ m

As $B_E = \frac{\mu_0}{4\pi}\frac{m}{r^3}$

$\therefore \quad m = \frac{B_E r^3}{\mu_0 / 4\pi}$

$= \frac{0.4 \times 10^{-4} \times (6.4 \times 10^6)^3}{10^{-7}} = 1.05 \times 10^{23}$ A m^2.

34. (a) : Here, $H_E = 0.25$ G and $\cos\delta = \frac{H_E}{B_E}$

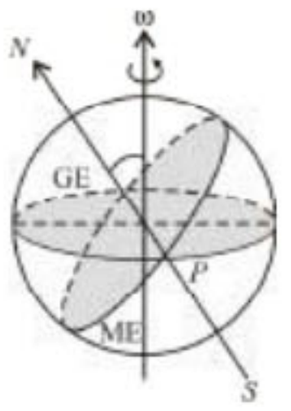
$\therefore$ The magnetic field of earth at the given location is

$$B_E = \frac{H_E}{\cos 60°} = \frac{0.25}{1/2} = 0.50 \text{ G}$$

35. (a) : As Britain is located close to North pole hence dip angle in Britain is greater and its approximate value is $\delta = 70°$.

36. (b): The angle of dip at a point on the geographical equator is positive, negative or zero depending upon the situation.

37. (b): Refer to the adjacent figure. The point P is at the intersection of geographical equator (GE) and magnetic equator (ME) then at this point dip = 0 and declination = 11.3°.



38. (b): As Melbourne is situated in southern hemisphere where north pole of earth's magnetic field lies therefore magnetic lines of force seem to come out of the ground.

39. (d): Relative magnetic permeability

$$\mu_r = \frac{\text{magnetic permeability of material } (\mu)}{\text{permeability of free space } (\mu)}$$

It is a dimensionless pure ratio and for paramagnetic materials $\mu_r > 1$.

40. (b):

Substance	Susceptibility at 300 K
Calcium	1.9×10^{-5}
Chromium	2.7×10^{-4}
Oxygen	2.1×10^{-6}
Tungsten	6.8×10^{-5}

Hence, out of given four paramagnetic substances chromium have highest value of susceptibility.

41. (c) : Magnetic susceptibility of diamagnetic substances does not depend upon the temperature. Hence, it remain constant due to change in temperature.

42. (a) **43. (c)** **44. (b)**

45. (a) : Permanent magnets are those substances that retain their ferromagnetic property for a long period of time at room temperature.

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Unit Test 3

- Electric Charges and Fields
- Electrostatic Potential and Capacitance
- Current Electricity • Moving Charges and Magnetism
- Magnetism and Matter

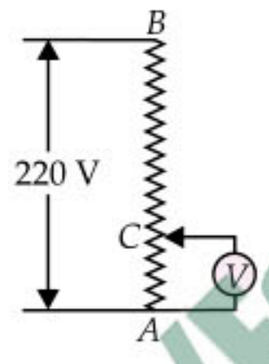
Unit test is complementary part of the learning process. It gives you a total insight whether the learning outcomes have been achieved or not. After doing daywise preparation, attempt these questions in exam like environment. This will assist you in finding particular area of weakness to work upon. An OMR sheet is given at the end to fill the correct answers.

All the Best!

Max. Marks : 180 **Time : 45 min.**

1. An electric charge 10^{-3} μC is placed at the origin (0, 0) of X - Y co-ordinate system. Two points A and B are situated at $(\sqrt{2}, \sqrt{2})$ and (2, 0) respectively. The potential difference between the points A and B will be
(a) 4.5 V (b) 9 V (c) zero (d) 2 V

2. A potential difference of 220 V is maintained across a 12000 Ω rheostat AB as shown in figure. The voltmeter V has a resistance of 6000 Ω and point C is at one fourth of the distance from A to B. What is the reading in the voltmeter ?



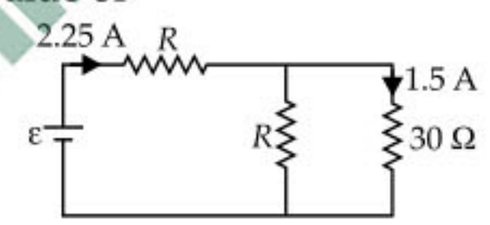
(a) 32 V (b) 36 V (c) 40 V (d) 42 V

3. A straight horizontal conducting rod of length 50 cm and mass 50 g is suspended by two vertical wires at its ends. A current of 5.0 A is set up in the rod through the wires. What magnetic field should be set up normal to the conductor in order that the tension in the wires is zero? (Take $g = 10\ m\ s^{-2}$)
(a) 0.05 T (b) 0.1 T (c) 0.2 T (d) 0.5 T

4. A magnet is suspended lengthwise from a spring and while it oscillates, the magnet moves in and out of the coil C connected to a galvanometer G. Then as the magnet oscillates,
(a) G shows no deflection
(b) G shows deflection on one side
(c) deflection of G to the left and right has constant amplitude
(d) deflection of G to the left and right has decreasing amplitude.

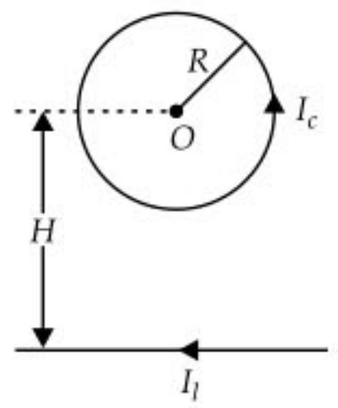
5. A parallel plate capacitor with air between the plates has a capacitance of 9 pF. The separation between the plates is d. The space between the plates is now filled with two dielectrics. One of the dielectrics has dielectric constant $K_1 = 3$ and thickness $d/3$ while the other one has dielectric constant $K_2 = 6$ and thickness $2d/3$. Capacitance of the capacitor is now
(a) 20.25 pF (b) 1.8 pF
(c) 45 pF (d) 40.5 pF

6. In the circuit shown, the value of
(a) $R = 15\ \Omega$
(b) $R = 30\ \Omega$
(c) $\varepsilon = 36$ V
(d) $\varepsilon = 180$ V



7. Two resistances are connected in two gaps of a metrebridge. The balance point is 20 cm from the zero end. A resistance of 15 Ω is connected in series with the smaller of the two. The null point shifts to 40 cm. The value of the smaller resistance in ohms is
(a) 3 (b) 6 (c) 9 (d) 12

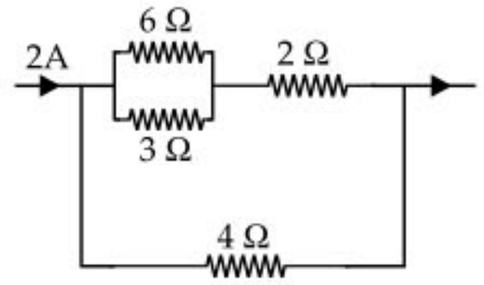
8. A circular loop of a wire and a long straight wire carry currents I_c and I_l respectively as shown in figure. Assuming that these are palced in the same plane, the magnetic field will be zero at the centre O of the loop, when separation H is



(a) $\frac{I_l R}{I_c \pi}$ (b) $\frac{I_c R}{I_l \pi}$ (c) $\frac{I_c \pi}{I_l R}$ (d) $\frac{I_l \pi}{I_c R}$

9. Two spherical conductors A and B of radii 1 mm and 2 mm are separated by a distance of 5 cm and are uniformly charged. If the spheres are connected by a conducting wire, then in equilibrium condition, the ratio of the magnitude of the electric fields at the surfaces of spheres A and B is
(a) 4 : 1 (b) 1 : 2 (c) 2 : 1 (d) 1 : 4

10. In the circuit shown in figure, the potential difference across 3 Ω is



(a) 2 V (b) 4 V (c) 8 V (d) 16 V

11. If E_a be the electric field strength of a short dipole at a point on its axial line and E_e that on the equatorial line at the same distance, then
(a) $E_e = 2E_a$ (b) $E_a = 2E_e$
(c) $E_a = E_e$ (d) $E_a = -2E_e$

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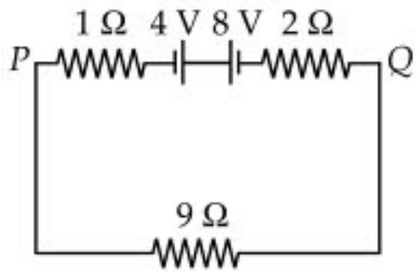
12. An electron is moving with the speed 5×10^6 m s^{-1} is shooted parallel to the electric field of intensity 1×10^3 N C^{-1}. Field is responsible for the retardation of motion of electron. Now evaluate the distance travelled by the electron before coming to rest (mass of electron $= 9 \times 10^{-31}$ kg, charge of electron $= 1.6 \times 10^{-19}$ C)
(a) 7 m (b) 0.7 mm (c) 7 cm (d) 0.7 cm

13. Two batteries of emf 4 V and 8 V with internal resistance 1 Ω and 2 Ω are connected in a circuit with a resistance of 9 Ω as shown in figure. The current and potential difference between the points P and Q are



(a) $\frac{1}{3}$ A and 3 V (b) $\frac{1}{6}$ A and 4 V
(c) $\frac{1}{9}$ A and 9 V (d) $\frac{1}{2}$ A and 12 V

14. A solenoid of 0.4 m length with 500 turns carries a current of 3 A. A coil of 10 turns and of radius 0.01 m carries a current of 0.4 A. The torque required to hold the coil with its axis at right angle to that of solenoid in the middle point of it is
(a) $6\pi^2 \times 10^{-7}$ N m (b) $3\pi^2 \times 10^{-7}$ N m
(c) $9\pi^2 \times 10^{-7}$ N m (d) $12\pi^2 \times 10^{-7}$ N m

15. Two wires of same metal have the same length but their cross sections are in the ratio 3 :1 . They are joined in series. The resistance of the thicker wire is 10 Ω. The total resistance of the combination is
(a) $\frac{5}{2}$ Ω (b) $\frac{40}{3}$ Ω (c) 40 Ω (d) 100 Ω

16. If a charged particle of charge 5 μC and mass 5 g is moving with constant speed 5 m s^{-1} in a uniform magnetic field B on a curve $x^2 + y^2 = 25$, where x and y are in metre. The value of magnetic field will be
(a) 1 kT along x-axis (b) 1 kT along z-axis
(c) 5 kT along the x-axis
(d) 1 kT along any line in the x-y plane

17. A conducting sphere of radius 10 cm is charged with 10 μC. Another uncharged sphere of radius 20 cm is allowed to touch it. After that if the spheres are separated, the surface density of charges on the spheres will be in the ratio of
(a) 1 : 4 (b) 1 : 2 (c) 1 : 3 (d) 2 : 1

18. A 100 V voltmeter having an internal resistance of 20 kΩ, when connected in series with a large resistance R across a 110 V line reads 5 V. The magnitude of resistance R is
(a) 210 kΩ (b) 310 kΩ (c) 420 kΩ (d) 440 kΩ

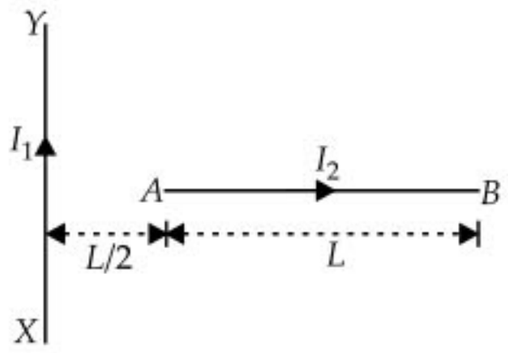
19. A moving coil galvanometer of resistance 100 Ω is used as an ammeter using a resistance 0.1 Ω. The maximum deflection current in the galvanometer is 100 μA. The minimum current in the circuit so that the ammeter shows maximum deflection is
(a) 100.1 mA (b) 1000.1 mA
(c) 10.01 mA (d) 1.01 mA

20. 10 mA current can pass through a galvanometer of resistance 25 Ω. What resistance in series should be connected through it, so that it is converted into a voltmeter of 100 V?
(a) 0.975 Ω (b) 99.75 Ω (c) 975 Ω (d) 9975 Ω

21. A solid conducting sphere of radius 10 cm is enclosed by a thin metallic shell of radius 20 cm. A charge $q = 20$ μC is given to the inner sphere. Find the heat generated in the process when the inner sphere is connected to the shell by a conducting wire.
(a) 24 J (b) 9 J (c) zero (d) 12 J

22. A conducting circular loop is placed in a uniform magnetic field 0.04 T with its plane perpendicular to the magnetic field. The radius of the loop starts sinking at 2 mm s^{-1}. The induced e.m.f. in the loop when the radius is 2 cm is
(a) 1.6 π μV (b) 3.2 π μV
(c) 4.8 π μV (d) 0.8 π μV

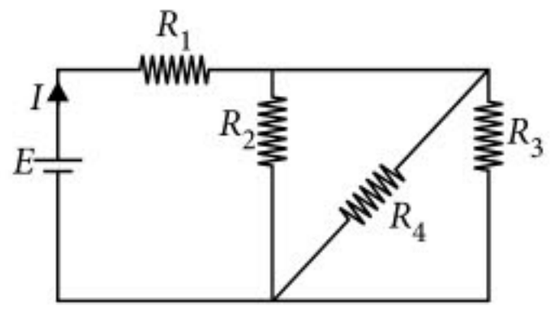
23. A conductor AB of length L carrying a current I_2, is placed perpendicular to a long straight conductor XY carrying current I_1, as shown in figure. The force on AB in magnitude is



(a) $\frac{3\mu_0 I_1 I_2}{2\pi}$ (b) $\frac{\mu_0 I_1 I_2}{2\pi} \ln 2$
(c) $\frac{\mu_0 I_1 I_2}{2\pi} \ln 3$ (d) $\frac{2\mu_0 I_1 I_2}{3\pi}$

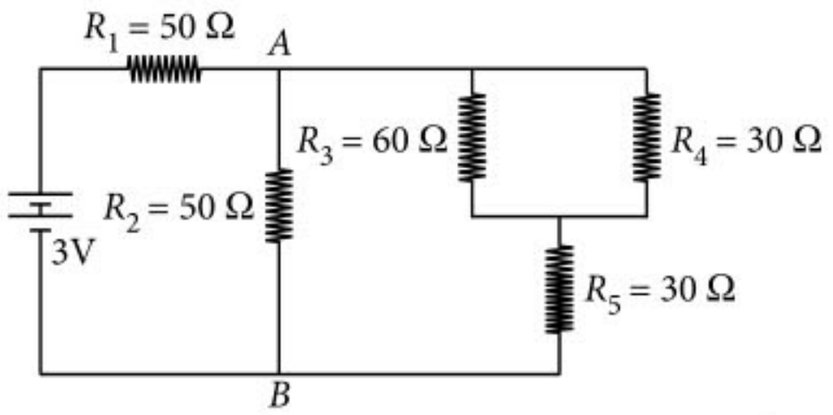
24. In a hydrogen atom, an electron revolves with a frequency of 6.8×10^9 MHz in an orbit of diameter 1.06 Å. The equivalent magnetic moment is
(a) 7.9×10^{-24} A m^2 (b) 9.7×10^{-24} A m^2
(c) 9.7×10^{24} A m^2 (d) 7.9×10^{24} A m^2

25. In the given circuit, $E = 6.0$ V, $R_1 = 100$ Ω, $R_2 = R_3 = 50$ Ω, $R_4 = 75$ Ω. The equivalent resistance of the circuit, in ohm is



(a) 11.875 (b) 26.31 (c) 118.75 (d) 16.39

26. In the given circuit, voltage across R_4 is



(a) 0.4 V (b) 0.6 V (c) 0.8 V (d) 1.0 V

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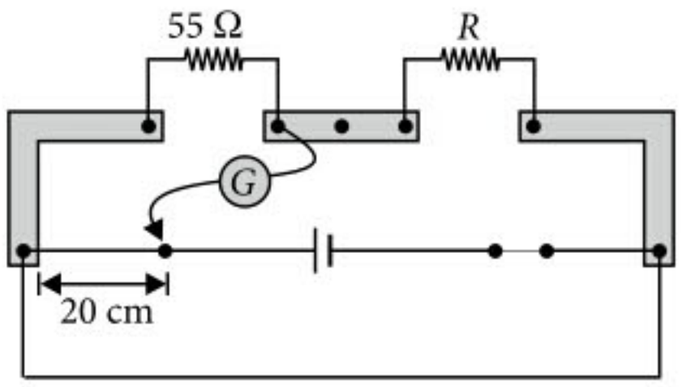
27. Figure shows a metre-bridge set up with null deflection in the galvanometer. The value of the unknown resistance R is



(a) 55 Ω (b) 13.75 Ω (c) 220 Ω (d) 110 Ω

28. A short circuit coil is placed in a time varying magnetic field. Electrical power is dissipated due to the current induced in the coil. If the number of turns were to be quadrupled and the wire radius halved, the electrical power dissipated would be

(a) halved (b) $\frac{1}{4}^{\text{th}}$

(c) doubled (d) quadrupled

29. A parallel plate capacitor has the space between its plates filled by two slabs of thickness $\frac{d}{2}$ each and dielectric constant K_1 and K_2. d is the plate separation of the capacitor. The capacity of the capacitor is

(a) $\frac{2\varepsilon_0 d}{A}\left(\frac{K_1+K_2}{K_1K_2}\right)$ (b) $\frac{2\varepsilon_0 A}{d}\left(\frac{K_1K_2}{K_1+K_2}\right)$

(c) $\frac{2\varepsilon_0 A}{A}(K_1+K_2)$ (d) $\frac{2\varepsilon_0 A}{d}\left(\frac{K_1+K_2}{K_1K_2}\right)$

30. A hollow cylinder has a charge q C within it. If ϕ is the electric flux in unit of V m associated with the curved surface B, the flux linked with the plane surface A in unit of V m will be

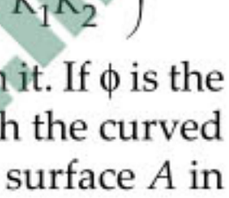
(a) $\frac{1}{2}\left(\frac{q}{\varepsilon_0}-\phi\right)$ (b) $\frac{q}{2\varepsilon_0}$

(c) $\frac{\phi}{3}$ (d) $\frac{q}{\varepsilon_0}-\phi$

31. An electric dipole is placed at an angle of 60° with an electric field of intensity 10^5 N C^{-1}. It experiences a torque equal to $8\sqrt{3}$ N m. Find the charge on the dipole, if the dipole length is 2 cm.

(a) 8×10^3 C (b) 8.54×10^{-4} C
(c) 8×10^{-3} C (d) 0.85×10^{-6} C

32. A thin, metallic spherical shell contains a charge Q on it. A point charge q is placed at the centre of the shell and another charge q_1 is placed outside it as shown in figure. All the three charges are positive. The force on the central charge due to the shell is



(a) towards left (b) towards right
(c) upward (d) zero

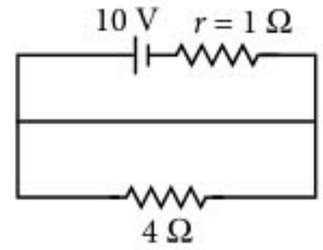
33. If a diamagnetic solution is poured into a U-tube and one arm of this U-tube is placed between the poles of a strong magnet, with the meniscus in line with the field, then the level of solution will

(a) rise (b) fall
(c) oscillate slowly (d) remain as such

34. The balancing length for a cell is 560 cm in a potentiometer experiment. When an external resistance of 10 Ω is connected in parallel to the cell, the balancing length changes by 60 cm. The internal resistance of the cell in ohms is

(a) 1.6 (b) 1.4 (c) 1.2 (d) 0.12

35. Potential difference across the terminals of the battery having internal resistance r as shown in the figure is



(a) 8 V
(b) 10 V
(c) 6 V
(d) zero

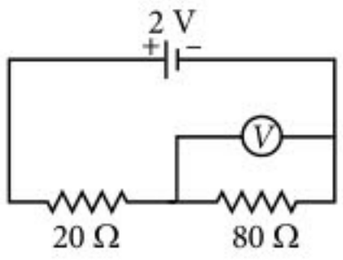
36. A beam of cathode rays is subjected to crossed electric field E and magnetic field B. The fields are adjusted such that the beam is not deflected. The specific charge of the cathode rays is given by (Take, V = potential difference between anode and cathode)

(a) $\frac{B^2}{2VE^2}$ (b) $\frac{2VB^2}{E^2}$ (c) $\frac{2VE^2}{B^2}$ (d) $\frac{E^2}{2VB^2}$

37. Two point charges q and $-q$ are placed at points X and Y, respectively. If V_1 is the electric potential at some point P due to q alone and V_2 be due to both charges, then [Position of P, X and Y are not same]

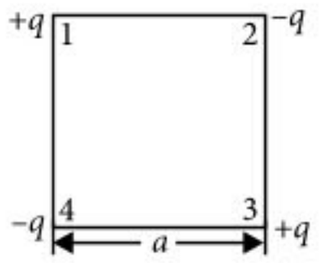
(a) $V_1 > V_2$ for all locations of P
(b) $V_1 = V_2$ for some points
(c) $V_1 > V_2$ for some points
(d) $V_1 < V_2$ for some points

38. In the figure shown below the e.m.f. of the cell is 2 V and internal resistance is negligible. The resistance of the voltmeter is 80 Ω. The reading of voltmeter will be



(a) 2.00 V (b) 1.33 V
(c) 1.60 V (d) 0.80 V

39. The work required to put the four charges at the corners of a square of side a, as shown in figure, is



(a) $\frac{1}{4\pi\varepsilon_0}\frac{q^2}{a}$ (b) $-\frac{2.6}{4\pi\varepsilon_0}\frac{q^2}{a}$

(c) $+\frac{2.6}{4\pi\varepsilon_0}\frac{q^2}{a}$ (d) none of these

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40. A moving coil galvanometer gives full scale deflection, when a current of 0.005A is passed through its coil. It is converted into a voltmeter reading upto 5 V using an external resistance of 975 Ω. What is the resistance of the galvanometer coil?
(a) 30 Ω (b) 25 Ω (c) 50 Ω (d) 40 Ω

41. A current I flows along the length of an infinitely long, straight, thin walled pipe. Then
(a) the magnetic field at all points inside the pipe is the same, but not zero
(b) the magnetic field is zero only on the axis of pipe
(c) the magnetic field is different at different point inside the pipe
(d) the magnetic field at any point inside the pipe is zero.

42. An electric cable of copper has just one wire of radius 9 mm. Its resistance is 5 Ω. This single copper wire of cable is replaced by 6 different well insulated copper wires each of radius 3 mm. The total resistance of the cable will now be equal to
(a) 7.5 Ω (b) 45 Ω (c) 90 Ω (d) 270 Ω

43. The torque required to hold a small circular coil of 10 turns, 2×10^{-4} m^2 area and carrying 0.5 A current in the middle of a long solenoid of 10^3 turns m^{-1} carrying 3 A current, with its axis perpendicular to the axis of the solenoid, is
(a) $12\pi \times 10^{-7}$ N m (b) $6\pi \times 10^{-7}$ N m
(c) $4\pi \times 10^{-7}$ N m (d) $2\pi \times 10^{-7}$ N m

44. The work done by electric field during the displacement of a negatively charged particle towards a fixed positively charged particle is 9 J. As a result the distance between the charges has been decreased by half. What work is done by the electric field over the first half of this distance?
(a) 3 J (b) 6 J (c) 1.5 J (d) 9 J

45. Two co-axial solenoids are made by winding thin insulated wire over a pipe of cross-sectional area $A = 10$ cm^2 and length = 20 cm. If one of the solenoids has 300 turns and the other 400 turns, their mutual inductance is
(a) $2.4\pi \times 10^{-4}$ H (b) $2.4\pi \times 10^{-5}$ H
(c) $4.8\pi \times 10^{-4}$ H (d) $4.8\pi \times 10^{-5}$ H

UNIT TEST 3 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____
(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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Electromagnetic Induction

Electromagnetic Induction

Whenever the magnetic flux linked with a coil (or a closed circuit) changes with time, an emf and a current are induced in the circuit. This phenomenon was first observed by Faraday and is called electromagnetic induction.

Faraday's law of electromagnetic induction

First law : Whenever the amount of magnetic flux linked with a circuit changes, an emf is induced in the circuit. This induced emf persists as long as the change in magnetic flux continues.

Second law : The magnitude of the induced emf is equal to the time rate of change of magnetic flux. Mathematically, induced emf is given by

$$\varepsilon = -\frac{d\phi}{dt}$$

where negative sign indicates the direction of ε.

In the case of a closely wound coil of N turns, change of flux associated with each turn, is the same. Therefore, the total induced emf is given by

$$\varepsilon = -N\frac{d\phi}{dt}$$

The induced emf can be increased by increasing the number of turns N of a closed coil.

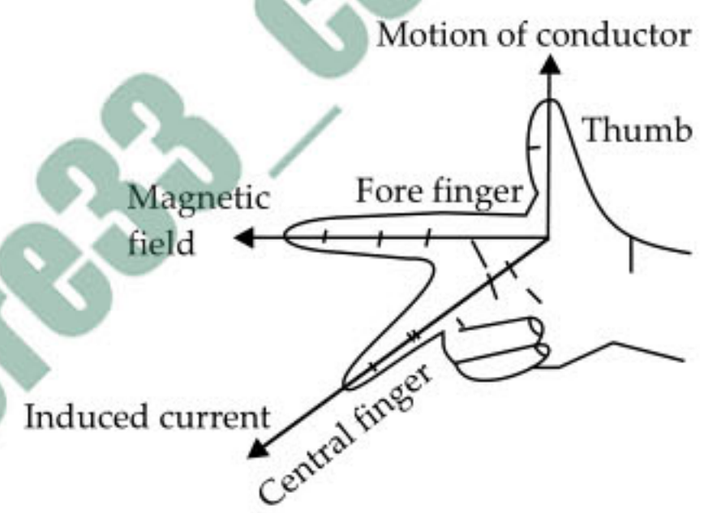
Here ϕ is the flux linked with one turn of the coil. If the circuit is closed, a current $I = \varepsilon/R$ is set up in it, where R is the resistance of the circuit.

Lenz's law

This law gives us the direction of induced emf. According to this law, the direction of induced emf in a circuit is such that it opposes the change in magnetic flux responsible for its production.Lenz's law is in accordance with the principle of conservation of energy.

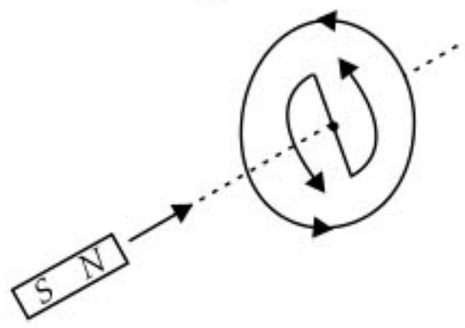
Fleming's right hand rule

Fleming's right hand rule also gives us the direction of induced emf or current, in a conductor moving in a magnetic field. According to this rule, if we stretch the fore finger, central finger and thumb of our right hand in mutually perpendicular directions such that fore finger points along the direction of the field and thumb is along the direction of motion of the conductor, then the central finger would give us the direction of induced current or emf. The direction of induced current or emf given by Lenz's law and Fleming's right hand rule is the same.

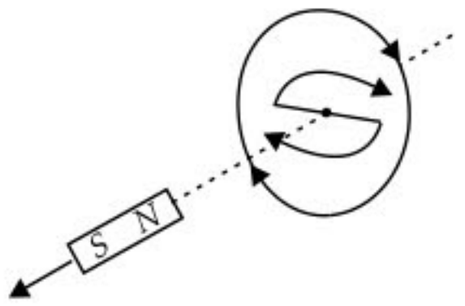


Applications of Lenz's law

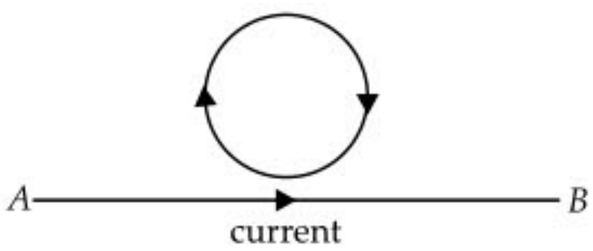
When a north pole of a bar magnet is moved towards a coil, the current induced in the coil will be in anticlockwise direction as shown in the figure.



When a north pole of a bar magnet is moved away from the coil, the current induced in the coil will be in clockwise direction as shown in the figure.



When current in a straight conductor AB is increased, induced current in loop will be in clockwise direction as shown in the figure. If current in AB is decreasing, the induced current in the loop will be in anticlockwise direction.



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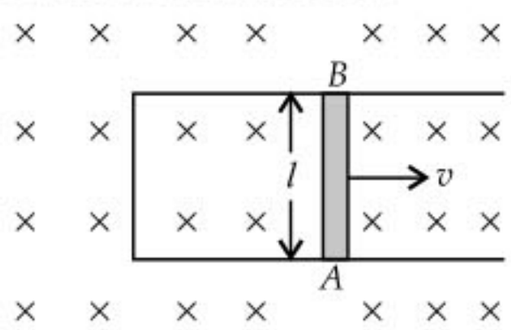
Some Important Formulae for Induced emf

When a conducting rod of length l, moves with a velocity v perpendicular to a uniform magnetic field B, the induced emf across its ends is

$$|\varepsilon| = Blv$$

This emf is known as motional emf.



If the rod makes an angle θ with the direction of the field, then induced emf is

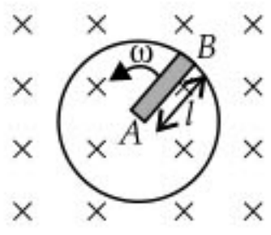
$$|\varepsilon| = Blv \sin\theta$$

When a conducting rod of length l is rotated perpendicular to a uniform magnetic field B, then induced emf between the ends of the rod is

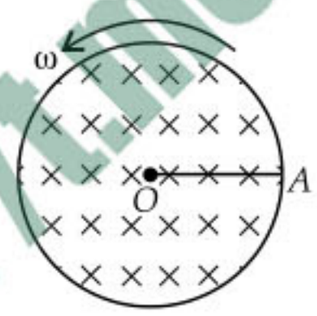
$$|\varepsilon| = \frac{B\omega l^2}{2} = \frac{B(2\pi\upsilon)l^2}{2}$$

$$|\varepsilon| = B\upsilon(\pi l^2) = B\upsilon A$$

where, ω is angular frequency and υ is frequency of rod, $A = \pi l^2$.



When a conducting solid disc of radius r is rotating with a uniform angular velocity ω with its plane perpendicular to a uniform magnetic field B, the emf induced between the centre and rim of disc is



$$|\varepsilon| = \frac{B\omega r^2}{2} = B\upsilon A$$

Eddy Currents

Eddy currents are basically the currents induced in the body of a conductor due to change in magnetic flux linked with the conductor.

The direction of eddy currents is given by Lenz's law, or Fleming's right hand rule.

Self Induction

Whenever the current passing through a coil or circuit changes, the magnetic flux linked with it will also change. As a result of this, an emf is induced in the coil or the circuit which opposes the change that causes it. This phenomenon is known as self induction and the emf induced is known as self induced emf or back emf.

When a current I flows through a coil and ϕ is the magnetic flux linked with the coil, then

$$\phi \propto I \text{ or } \phi = LI$$

where L is coefficient of self induction or self inductance of the coil.

The self induced emf is

$$\varepsilon = -\frac{d\phi}{dt} = -L\frac{dI}{dt}$$

The SI unit of L is henry (H) and its dimensional formula is $[ML^2T^{-2}A^{-2}]$.

Self inductance of a solenoid is $L = \mu_0 n^2 lA$

where l is length of the coil solenoid, n is number of turns per unit length of a solenoid and A is area of cross section of the solenoid.

Self inductance of a circular coil is

$$L = \frac{\mu_0 N^2 \pi R}{2}$$

where R is the radius of a coil and N is the number of turns

Mutual Induction

Whenever the current passing through a coil or circuit changes, the magnetic flux linked with a neighbouring coil or circuit will also change. Hence an emf will be induced in the neighbouring coil or circuit. This phenomenon is known as mutual induction. The coil or circuit in which the current changes is known as primary while the other in which emf is set up is known as secondary.

Let I_P be the current flowing through primary coil at any instant. If ϕ_S is the flux linked with secondary coil then

$$\phi_S \propto I_P \text{ or } \phi_S = MI_P$$

where M is coefficient of mutual inductance of two coils.

The emf induced in the secondary coil is given by

$$\varepsilon_S = -M\frac{dI_P}{dt}$$

The SI unit of M is henry (H) and its dimensional formula is $[ML^2T^{-2}A^{-2}]$.

Coefficient of coupling (K)

Coefficient of coupling of two coils is a measure of the coupling between the two coils and is given by

$$K = \frac{M}{\sqrt{L_1 L_2}}$$

where L_1 and L_2 are coefficients of self inductance of the two coils and M is coefficient of mutual inductance of the two coils.

The coefficient of mutual inductance of two long co-axial solenoids, each of length l, area of cross section A, wound on air core is

$$M = \frac{\mu_0 N_1 N_2 A}{l}$$

where N_1, N_2 are total number of turns of the two solenoids.

Combination of Inductances

Two inductors of self-inductances L_1 and L_2 are kept so far apart that their mutual inductance is zero. These are connected in series. Then the equivalent inductance is

$$L = L_1 + L_2$$

Two inductors of self-inductance L_1 and L_2 are connected in series and they have mutual inductance M. Then the

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equivalent inductance of the combination is

$$L = L_1 + L_2 \pm 2M$$

The plus sign occurs if windings in the two coils are in the same sense, while minus sign occurs if windings are in opposite sense.

Two inductors of self-inductors L_1 and L_2 are connected in parallel. The inductors are so far apart that their mutual inductance is negligible. Then their equivalent inductance is

$$L = \frac{L_1 L_2}{L_1 + L_2} \quad \text{or} \quad \frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2}$$

Energy Stored in an Inductor

When a current I flows through an inductor, the energy stored in it and it is given by

$$U = \frac{1}{2} LI^2$$

The energy stored in an inductor is in the form of magnetic energy.

AC Generator / Dynamo

An ac generator/dynamo produces alternating current energy from mechanical energy of rotation of a coil. It is based on the phenomenon of electromagnetic induction. The form of emf induced is $\varepsilon = \varepsilon_0 \sin\omega t$, where $\varepsilon_0 = NAB\omega$, max. emf induced. Here, N is total number of turns in the coil, A is face area of the coil, B is strength of magnetic field applied and ω is angular velocity of the armature coil.

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EXAM DRILL

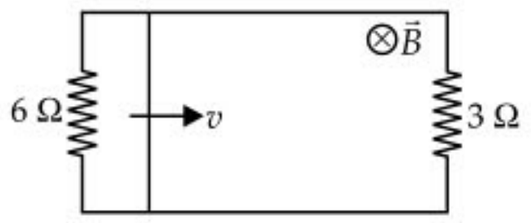
1. A conducting ring of radius 1 m is placed in a uniform magnetic field B of 0.01 T oscillating with frequency 100 Hz with its plane at right angles to B. What will be induced electric field?

(a) π V m^{-1} (b) 0.5 V m^{-1}
(c) 10 V m^{-1} (d) 62 V m^{-1}

2. The magnetic flux linked with a circuit of resistance 100 Ω increases from 10 to 60 Wb. The amount of induced charge that flows in the circuit in coulomb is

(a) 0.5 (b) 5
(c) 50 (d) 100

3. A rectangular loop with a sliding connector of length l = 1.0 m is situated in a uniform magnetic field B = 2 T, perpendicular to the plane of the loop. Resistance of connector is r = 2 Ω. Two resistances of 6 Ω and 3 Ω are connected as shown in figure. The external force required to keep the connector moving with a constant velocity v = 2 m s^{-1} is



(a) 2 N (b) 1 N
(c) 4 N (d) 6 N

4. Two solenoids of equal number of turns have their lengths and the radii in the same ratio 1 : 2. The ratio of their self-inductances will be

(a) 1 : 2 (b) 2 : 1
(c) 1 : 1 (d) 1 : 4

5. A 0.1 m long conductor carrying a current of 50 A is held perpendicular to a magnetic field of 1.25 mT. The mechanical power required to move the conductor with a speed of 1 m s^{-1} is

(a) 62.5 mW (b) 625 mW
(c) 6.25 mW (d) 12.5 mW

6. A coil of inductance 300 mH and resistance 2 Ω is connected to a source of voltage 2 V. The current reaches half of its steady state value in

(a) 0.05 s (b) 0.1 s
(c) 0.15 s (d) 0.3 s

7. What will happen to the inductance L of a solenoid when the number of turns and the length are doubled keeping the area of cross-section same?

(a) $\frac{L}{2}$ (b) L
(c) $2L$ (d) $4L$

8. A circular copper disc 10 cm in diameter rotates at 1800 rev per minute about an axis through its centre and at right angles to disc. A uniform field of induction B of 1 weber m^{-2} is perpendicular to disc. What potential difference is developed between the axis of the disc and the rim?

(a) 0.023 V (b) 0.23 V
(c) 23 V (d) 230 V

9. The magnetic flux lined with the coil varies with time as $\phi = 3t^2 + 4t + 9$. The magnitude of induced emf at t = 2 s is

(a) 9 V (b) 16 V
(c) 3 V (d) 4 V

10. A varying magnetic flux linking a coil is given by $\phi = xt^2$. If at a time t = 3 s, the emf induced is 9 V, then the value of x is

(a) 0.66 Wb s^{-2} (b) 1.5 Wb s^{-2}
(c) −0.66 Wb s^{-2} (d) −1.5 Wb s^{-2}

11. A long solenoid has 800 turns per metre length of solenoid. A current of 1.6 A flows through it. The magnetic induction at the end of the solenoid on its axis is

(a) 16×10^{-4} T (b) 8×10^{-4} T
(c) 32×10^{-4} T (d) 4×10^{-4} T

12. An electromagnet has stored 648 J of magnetic energy when a current of 9 A exists in its coils. What average emf is induced if the current is reduced to zero in 0.45 s?

(a) 320 V (b) 620 V
(c) 260 V (d) 230 V

13. A metal rod of length 2 m is rotating with an angular velocity of 100 rad s^{-1} in a plane perpendicular to a uniform magnetic field of 0.3 T. The potential difference between the ends of the rod is

(a) 30 V (b) 40 V
(c) 60 V (d) 600 V

14. Two coils A and B are separated by a certain distance. If a current of 4 A flows through A, a magnetic flux of 10^{-3} Wb passes through B (no current through B). If no current passes through A and a current of 2 A passes through B, then the flux through A is

(a) 5×10^{-3} Wb (b) 4×10^{-4} Wb
(c) 5×10^{-4} Wb (d) 2×10^{-3} Wb

15. A coil of area 0.4 m^2 has 100 turns. A magnetic field of 0.04 Wb m^{-2} is acting normal to the coil surface. If this magnetic field is reduced to zero in 0.01 s, then the induced emf in the coil is

(a) 160 V (b) 250 V
(c) 270 V (d) 320 V

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16. The magnetic flux linked with a coil of N turns of area of cross section A held with its plane parallel to the field B is

(a) $\frac{NAB}{2}$ (b) NAB

(c) $\frac{NAB}{4}$ (d) zero

17. A jet plane is travelling west at the speed of 1600 km h^{-1}. The voltage difference developed between the ends of the wing having a span of 20 m, if the earth's magnetic field at the location has a magnitude of 5×10^{-4} T and the dip angle is 30° is

(a) 4.1 V (b) 2.2 V

(c) 3.2 V (d) 3.8 V

18. A long solenoid with 10 turns per cm has a small loop of area 3 cm^2 placed inside, normal to the axis of the solenoid. If the current carried by the solenoid changes steadily from 2 A to 4 A in 0.2 s, what is the induced voltage in the loop, while the current is changing?

(a) 4.2×10^{-8} V (b) 2.8×10^{-8} V

(c) 7.3×10^{-6} V (d) 3.8×10^{-6} V

19. A square loop of side 12 cm and resistance 0.60 Ω is placed vertically in the east-west plane. A uniform magnetic field of 0.10 T is set up across the plane in north-east direction. The magnetic field is decreased to zero in 0.6 s at a steady rate. The magnitude of current during this time interval is

(a) 1.42×10^{-3} A (b) 2.72×10^{-3} A

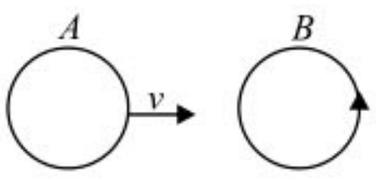
(c) 3.41×10^{-3} A (d) 4.21×10^{-3} A

20. A magnetic flux through a stationary loop with a resistance R varies during the time interval τ as $\phi = at(\tau - t)$. What is the amount of heat generated in the loop during that time ?

(a) $\frac{a^2\tau^3}{4R}$ (b) $\frac{a^2\tau^3}{3R}$

(c) $\frac{a^2\tau^3}{6R}$ (d) $\frac{a^2\tau^3}{2R}$

21. Two coils, A and B are as shown in the figure. A current starts flowing in B as shown, when A is moved toward B and stops when A stops moving.



The current in A is counterclockwise. B is kept stationary when A moves. We can infer that

(a) there is a constant current in the clockwise direction of A.

(b) there is a no current in A.

(c) there is a varying current in A.

(d) there is a constant current in the counterclockwise direction in A.

22. Two solenoids of equal number of turns have their lengths and the radii in the same ratio 1 : 2. The ratio of their self inductances will be

(a) 1 : 2 (b) 2 : 1

(c) 1 : 1 (d) 1 : 4

23. If the number of turns per unit length of a coil of solenoid is doubled, the self-inductance of the solenoid will

(a) remain unchanged (b) be halved

(c) be doubled (d) become four times

24. A circular coil of radius 6 cm and 20 turns rotates about its vertical diameter with an angular speed of 40 rad s^{-1} in a uniform horizontal magnetic field of magnitude 2×10^{-2} T. If the coil form a closed loop of resistance 8 Ω, then the average power loss due to joule heating is

(a) 2.07×10^{-3} W (b) 1.23×10^{-3} W

(c) 3.14×10^{-3} W (d) 1.80×10^{-3} W

25. A pair of adjacent coils has a mutual inductance of 2.5 H. If the current in one coil changes from 0 to 40 A in 0.8 s, then the change in flux linked with the other coil is

(a) 100 Wb (b) 120 Wb

(c) 200 Wb (d) 250 Wb

26. A wheel with 20 metallic spokes each of length 0.8 m long is rotated with a speed of 120 revolution per minute in a plane normal to the horizontal component of earth magnetic field H at a place. If $H = 0.4 \times 10^{-4}$ T at the place, then induced emf between the axle and the rim of the wheel is

(a) 2.3×10^{-4} V (b) 3.1×10^{-4} V

(c) 2.9×10^{-4} V (d) 1.61×10^{-4} V

27. A metal conductor of length 1 m rotates vertically about one of its ends with an angular velocity 5 rad s^{-1}. If the horizontal component of earth's magnetic field is 0.2×10^{-4} T, then the emf developed between the ends of the conductor is

(a) 5 μV (b) 5 mV

(c) 50 μV (d) 50 mV

28. Two conducting circular loops of radii R_1 and R_2 are placed in the same plane with their centres coinciding. If $R_1 > R_2$ the mutual inductance M between them will be directly proportional to

(a) $\frac{R_1}{R_2}$ (b) $\frac{R_2}{R_1}$

(c) $\frac{R_1^2}{R_2}$ (d) $\frac{R_2^2}{R_1}$

29. A rectangular loop of sides 6 cm and 2 cm with a small cut is moving out of a region of uniform magnetic field of magnitude 0.4 T directed normal to the loop. The voltage developed across the cut if velocity of loop is 2 cm s^{-1} in a direction normal to the longer side is

(a) 3.8×10^{-4} V (b) 4.8×10^{-4} V

(c) 2.2×10^{-2} V (d) 3.2×10^{-2} V

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30. A small flat search coils of area 4 cm^2 with 20 closely wound turns is positioned normal to the field direction and then quickly snatched out of the field region. The total charge flowing in the coil (measured by a ballistic galvanometer connected to the coil) is 7.5 mC. The resistance of the coil and galvanometer is 0.8 Ω. The field strength of the magnet is

(a) 1.25 T (b) 0.50 T
(c) 0.75 T (d) 2.10 T

31. A conducting ring of radius r is placed in a varying magnetic field perpendicular to the plane of the ring. If the rate at which the magnetic field varies is x, the electric field intensity at any point of the ring is

(a) rx (b) $\frac{rx}{2}$
(c) $2rx$ (d) $\frac{4r}{x}$

32. An air cored solenoid with length 20 cm, area of cross section 20 cm^2 and number of turns 400 carries a current 2 A. The current is suddenly switched off within 10^{-3} s. The average back emf induced across the ends of the open switch in the circuit is (ignore the variation in magnetic field near the ends of the solenoid)

(a) 2 V (b) 4 V
(c) 3 V (d) 5 V

33. A rod of length l rotates with a uniform angular velocity ω about an axis passing through its middle point but normal to its length in a uniform magnetic field of induction B with its direction parallel to the axis of rotation. The induced emf between the two ends of the rod is

(a) $\frac{Bl^2\omega}{2}$ (b) zero
(c) $\left(\frac{Bl^2\omega}{8}\right)$ (d) $2Bl^2\omega$

34. The magnetic flux through a coil perpendicular to its plane and directed into paper is varying according to the relation $\phi = (2t^2 + 4t + 6)$ mWb. The emf induced in the loop at $t = 4$ s is

(a) 0.12 V (b) 2.4 V
(c) 0.02 V (d) 1.2 V

35. A 2 m long solenoid with diameter 2 cm and 2000 turns has a secondary coil of 1000 turns wound closely near its midpoint. The mutual inductance between the two coils is

(a) 2.4×10^{-4} H (b) 3.9×10^{-4} H
(c) 1.28×10^{-3} H (d) 3.14×10^{-3} H

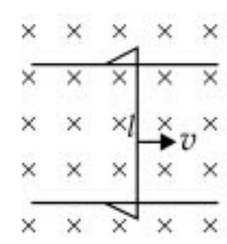
36. A 10 V battery connected to 5 Ω resistance coil having inductance 10 H through a switch drives a constant current in the circuit. The switch is suddenly opened and the time taken to open it is 2 ms. The average emf induced across the coil is

(a) 4×10^4 V (b) 2×10^4 V
(c) 2×10^2 V (d) 1×10^4 V

37. There is a uniform magnetic field directed perpendicular and into the plane of the paper. An irregular shaped conducting loop is slowly changing into a circular loop in the plane of the paper. Then

(a) current is induced in the loop in the anti-clockwise direction
(b) current is induced in the loop in the clockwise direction.
(c) ac is induced in the loop.
(d) no current in induced in the loop.

38. The figure shows a wire sliding on two parallel conducting rails placed at a separation l. A magnetic field B exists in a direction perpendicular to the plane of the rails. The force required to keep the wire moving at a constant velocity v will be



(a) evB (b) $\frac{\mu_0 Bv}{4\pi l}$
(c) Blv (d) zero

39. In a uniform magnetic field B a wire in the form of a semicircle of radius r rotates about the diameter of the circle with angular frequency ω. The axis of rotation is perpendicular to the field. If the total resistance of the circuit is R, the mean power generated per period of rotation is

(a) $\frac{B\pi r^2\omega}{2R}$ (b) $\frac{(B\pi r^2\omega)^2}{8R}$
(c) $\frac{(B\pi r\omega)^2}{2R}$ (d) $\frac{(B\pi r\omega^2)^2}{8R}$

40. The self inductance of a coil having 400 turns is 10 mH. The magnetic flux through the cross section of the coil corresponding to current 2 mA is

(a) 4×10^{-5} Wb (b) 2×10^{-3} Wb
(c) 3×10^{-5} Wb (d) 8×10^{-3} Wb

41. A copper rod of length l rotates about its end with angular velocity ω in a uniform magnetic field B. The emf developed between the ends of the rod if the field is normal to the plane of rotation is

(a) $B\omega l^2$ (b) $\frac{1}{2}B\omega l^2$
(c) $2\,B\omega l^2$ (d) $\frac{1}{4}B\omega l^2$

42. A current of 1 A through a coil of inductance of 200 mH is increasing at a rate of 0.5 A s^{-1}. The energy stored in the inductor per second is

(a) 0.5 J s^{-1} (b) 5.0 J s^{-1}
(c) 0.1 J s^{-1} (d) 2.0 J s^{-1}

43. Two coils A and B having turns 300 and 600 respectively are placed near each other. On passing a current of 3.0 ampere in A, the flux linked with A

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is 1.2×10^{-4} Wb and with B it is 9.0×10^{-5} Wb. The mutual inductance of the system is

(a) 4×10^{-5} H (b) 3×10^{-5} H
(c) 2×10^{-5} H (d) 1.8×10^{-2} H

44. A circular disc of radius 0.2 m is placed in a uniform magnetic field of induction $\left(\frac{1}{\pi}\right)$ Wb m^{-2} in such a way that its axis makes an angle of 60° with $\vec{B}$. The magnetic flux linked with the disc is

(a) 0.02 Wb (b) 0.06 Wb
(c) 0.08 Wb (d) 0.01 Wb

45. A solenoid of length 30 cm with 10 turns per centimetre and area of cross-section 40 cm^2 completely surrounds another co-axial solenoid of same length, area of cross-section 20 cm^2 with 40 turns per centimetre. The mutual inductance of the system is

(a) 10 H (b) 8 H
(c) 3 mH (d) 30 mH

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DAY 20 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ◉

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____

(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (b) : Here, $r = 1$ m, $B = 0.01$ T, $t = \frac{1}{\upsilon} = \frac{1}{100}$ s

Induced emf, $|\varepsilon| = \frac{d\phi}{dt}$

$$|\varepsilon| = \frac{BA}{t} = \frac{B\pi r^2}{t} = \frac{0.01 \times \pi(1)^2}{1/100} = \pi \text{ V}$$

Induced electric field,

$$E = \frac{|\varepsilon|}{l} = \frac{\varepsilon}{2\pi r} = \frac{\pi}{2\pi \times 1} = 0.5 \text{ V m}^{-1}$$

2. (a) : The amount of induced charge is given by

$$q = \frac{1}{R}\Delta\phi = \frac{1}{R}(\phi_2 - \phi_1) = \frac{1}{100}(60 - 10)$$

(where $\phi_1 = 10$ Wb, $\phi_2 = 60$ Wb, $R = 100\ \Omega$)

$$q = \frac{50}{100} = 0.5 \text{ C}$$

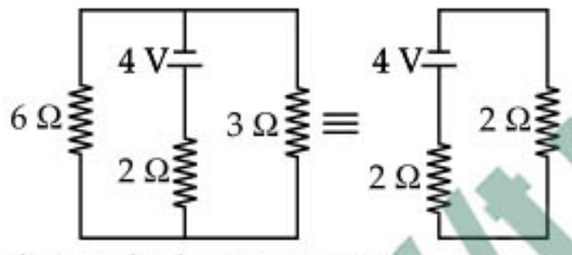
3. (a) : Motional emf induced in the connector

$$\varepsilon = Blv = 2(1)(2) = 4 \text{ V}$$

This acts as a cell of emf 4 V and internal resistance 2 Ω. 6 Ω and 3 Ω resistors are in parallel.

$$\therefore \quad \frac{1}{R_p} = \frac{1}{6} + \frac{1}{3} = \frac{1+2}{6} = \frac{3}{6} = \frac{1}{2}$$

$$R_p = 2\ \Omega$$



$\therefore$ Current through the connector,

$$= \frac{\varepsilon}{R_p + r} = \frac{4}{2+2} = 1 \text{ A}$$

Magnetic force on the connector

$$= BIl = 2(1)(1) = 2 \text{ N}$$

4. (a) : Self-inductance of a solenoid is given by,

$$L = \frac{\mu_0 N^2 \pi r^2}{l}$$

$$\therefore \quad \frac{L_1}{L_2} = \left(\frac{r_1}{r_2}\right)^2 \times \left(\frac{l_2}{l_1}\right) = \left(\frac{1}{2}\right)^2 \times \left(\frac{2}{1}\right) \quad \text{or} \quad \frac{L_1}{L_2} = \frac{1}{2}$$

5. (c) : Here, $l = 0.1$ m, $v = 1$ m s^{-1}

$I = 50$ A, $B = 1.25$ mT $= 1.25 \times 10^{-3}$ T

The induced emf is, $\varepsilon = Blv$

The mechanical power is

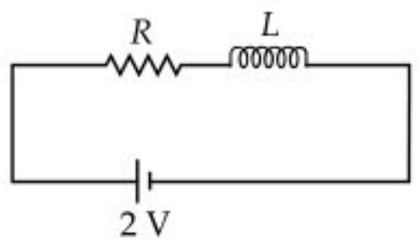
$$P = \varepsilon I = BlvI = 1.25 \times 10^{-3} \times 0.1 \times 1 \times 50$$
$$= 6.25 \times 10^{-3} \text{ W} = 6.25 \text{ mW}$$

6. (b) : The current at any instant is given by

$$\Rightarrow \quad I = I_0(1 - e^{-Rt/L})$$

$$\Rightarrow \quad \frac{I_0}{2} = I_0(1 - e^{-Rt/L})$$

$$\text{or} \quad \frac{1}{2} = (1 - e^{-Rt/L})$$



$$\text{or} \quad e^{-Rt/L} = \frac{1}{2} \quad \text{or} \quad \frac{Rt}{L} = \ln 2$$

$$\therefore \quad t = \frac{L}{R}\ln 2 = \frac{300 \times 10^{-3}}{2} \times 0.693$$
$$= 150 \times 0.693 \times 10^{-3} = 0.10395 \text{ s} = 0.1 \text{ s}$$

7. (c) : In case of a solenoid as $B = \mu_0 nI$,

$\phi = B(nlS) = \mu_0 n^2 lSI$ and hence

$$L = \frac{\phi}{I} = \mu_0 n^2 lS = \mu_0 \frac{N^2}{l} S \quad \left(\text{as } n = \frac{N}{l}\right)$$

When N and l are doubled, then

$$L' = \mu_0 \frac{(2N)^2}{2l} S = 2\mu_0 \frac{N^2}{l} S = 2L$$

i.e., inductance of the solenoid will be doubled.

8. (b) : Here, $l = r = 5$ cm $= 5 \times 10^{-2}$ m,

$$\omega = 2\pi\left(\frac{1800}{60}\right) \text{ rad/s}$$

$$= 60\pi \text{ rad/s}, \quad B = 1 \text{ Wb m}^{-2}$$

$$\varepsilon = \frac{1}{2}Bl^2\omega = \frac{1}{2} \times 1 \times (5 \times 10^{-2})^2 \times 60\pi = 0.23 \text{ V}$$

9. (b) : $\phi = 3t^2 + 4t + 9$

$$|\varepsilon| = \frac{d\phi}{dt} = \frac{d}{dt}(3t^2 + 4t + 9)$$

$$|\varepsilon| = 6t + 4$$

At $t = 2$ s; $|\varepsilon| = 6 \times 2 + 4 = 16$ V

10. (d) : Given: $\phi = xt^2$

$$\therefore \quad \frac{d\phi}{dt} = 2xt$$

Induced emf $\varepsilon = -\frac{d\phi}{dt} = -2xt$

$$\therefore \quad x = -\frac{\varepsilon}{2t}$$

At $t = 3$ s, $x = -\frac{9}{2 \times 3} = -1.5$ Wb s^{-2}

11. (b) : $B = \frac{\mu_0 nI}{2} = \frac{(4\pi \times 10^{-7}) \times 800 \times 1.6}{2} = 8 \times 10^{-4}$ T

12. (a) : Magnetic energy, $U = \frac{1}{2}LI^2$

$$\therefore \ L = \frac{2U}{I^2} = \frac{2 \times 648}{(9)^2} = 16 \text{ H}$$

Induced emf,

$$\varepsilon = -L\frac{dI}{dt} = \frac{-(16 \text{ H})(0 - 9 \text{ A})}{0.45 \text{ s}} = 320 \text{ V}$$

13. (c) : Here, $l = 2$ m, $\omega = 100$ rad s^{-1}, $B = 0.3$ T

The potential difference between the ends of rod is

$$\varepsilon = \frac{1}{2}B\omega l^2 = \frac{1}{2} \times 0.3 \times 100 \times (2)^2 = 60 \text{ V}$$

14. (c) : Magnetic flux linked with coil

$$\phi_B = MI_A$$

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$\therefore \quad M = \frac{\phi_B}{I_A} = \frac{10^{-3}}{4}$ henry

Magnetic flux linked with coil A

$\phi_A = MI_B = \frac{10^{-3}}{4} \times 2 = 5 \times 10^{-4}$ Wb

15. (a) : Here, $A = 0.4\ m^2$, $N = 100$, $dB = 0.04$ Wb m^{-2}, $dt = 0.01$ s

As $\varepsilon = \frac{d\phi}{dt} = NA\frac{dB}{dt}$ $(\because \phi = BA)$

$= 100 \times 0.4 \times \frac{0.04}{0.01} = 160$ V

16. (d) : Magnetic flux linked with a coil

$\phi = NBA\cos\theta$

Since the magnetic field B is parallel to the area A,

i.e., $\theta = 90°$.

$\therefore \quad \phi = 0$

17. (b) : Here, $v = 1600$ km $h^{-1} = 1600 \times \frac{5}{18}$ m s^{-1}

$= 444$ m s^{-1}

$l = 20$ m , $B = 5 \times 10^{-4}$ T and $\delta = 30°$

As $\varepsilon = Blv = Vlv$

(where V is the vertical component of earth's field)

$= (B \sin\delta)\, lv$ $(\because V = B\sin\delta)$

$= 5 \times 10^{-4} \sin 30° \times 20 \times 444$

$= 2.2$ V

18. (d) : Here, $\frac{N}{l} = 10$ turns per cm $= 1000$ turns per m

$A = 3\ cm^2 = 3 \times 10^{-4}\ m^2$

or $\frac{dI}{dt} = \frac{4-2}{0.2} = 10\ A\,s^{-1}$

Also $\varepsilon = \frac{d\phi}{dt} = \frac{d}{dt}(BA) = A\frac{d}{dt}\left(\mu_0 \frac{N}{l} I\right)$

$= A\mu_0\left(\frac{N}{l}\right)\frac{dI}{dt}$

$= 3 \times 10^{-4} \times 4\pi \times 10^{-7} \times 1000 \times 10 = 3.8 \times 10^{-6}$ V

19. (b) : Here, Area $A = l^2 = (12\ cm)^2 = 1.4 \times 10^{-2}\ m^2$

$R = 0.60\ \Omega$, $B_1 = 0.10$ T, $\theta = 45°$

$B_2 = 0$, $dt = 0.6$ s

Initial flux, $\phi_1 = B_1 A\cos\theta$

$= 0.10 \times 1.4 \times 10^{-2} \times \cos 45°$

$= 9.8 \times 10^{-4}$ Wb

Final flux, $\phi_2 = 0$

Induced emf, $\varepsilon = \frac{|d\phi|}{dt} = \frac{|\phi_2 - \phi_1|}{dt}$

$= \frac{|9.8 \times 10^{-4}|}{0.6\ s} = 1.63 \times 10^{-3}$ V

Current, $I = \frac{\varepsilon}{R} = \frac{1.63 \times 10^{-3}}{0.6} = 2.72 \times 10^{-3}$ A

20. (b) : The flux through the stationary loop is

$\phi = at(\tau - t)$

Induced emf,

$\varepsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}[at(\tau - t)] = -[a\tau - 2at] = (2at - a\tau)$

The amount of heat generated in the loop during a small time interval dt is

$dQ = \frac{\varepsilon^2}{R}dt = \frac{(2at - a\tau)^2}{R}dt$

Hence, the total amount of heat generated is

$Q = \int_0^\tau \frac{(2at - a\tau)^2}{R}dt = \frac{1}{R}\int_0^\tau (4a^2t^2 + a^2\tau^2 - 4a^2\tau t)dt$

$= \frac{1}{R}\left[\frac{4}{3}a^2t^3 + a^2\tau^2 t - \frac{4}{2}a^2\tau t^2\right]_0^\tau = \frac{1}{3}\frac{a^2\tau^3}{R}$

21. (d) : Coil A must be carrying a constant current in counter clockwise direction. Because of that, when A moves towards B, current induced in B is counterclockwise direction as per Lenz's law. The current in B would stop when A stops moving.

22. (a) : Self inductance of a solenoid,

$L = \frac{\mu_0 N^2 A}{l} = \frac{\mu_0 N^2 \pi r^2}{l}$

where l is the length of the solenoid, N is the total number of turns of the solenoid and A is the area of cross-section of the solenoid.

$\therefore \quad \frac{L_1}{L_2} = \left(\frac{N_1}{N_2}\right)^2\left(\frac{r_1}{r_2}\right)^2\left(\frac{l_2}{l_1}\right)$

Here, $N_1 = N_2$, $\frac{l_1}{l_2} = \frac{1}{2}$, $\frac{r_1}{r_2} = \frac{1}{2}$

$\therefore \quad \frac{L_1}{L_2} = \left(\frac{1}{2}\right)^2\left(\frac{2}{1}\right) = \frac{1}{2}$

23. (d) : Self inductance of a solenoid $= \mu_0 n^2 Al$

where n is the number of turns per length.

$\therefore$ Self inductance is directly proportional to n^2. Self inductance becomes 4 times when n is doubled.

24. (a) : Here, $r = 6$ cm $= 6 \times 10^{-2}$ m, $N = 20$, $\omega = 40$ rad s^{-1}

$B = 2 \times 10^{-2}\ T$, $R = 8\ \Omega$

Maximum emf induced, $\varepsilon = NAB\omega$

$= N(\pi r^2)B\omega$

$= 20 \times \pi \times (6 \times 10^{-2})^2 \times 2 \times 10^{-2} \times 40$

$= 0.18$ V

Average value of emf induced over a full cycle

$\varepsilon_{av} = 0$

Maximum value of current in the coil,

$I = \frac{\varepsilon}{R} = \frac{0.18}{8} = 0.023$ A

Average power dissipated,

$P = \frac{\varepsilon I}{2} = \frac{0.18 \times 0.023}{2} = 2.07 \times 10^{-3}$ W

25. (a) : Given, $M = 2.5$ H, $\frac{dI}{dt} = \frac{40-0}{0.8} = 50\ A\,s^{-1}$

Also, $\varepsilon = M\frac{dI}{dt} = \frac{d\phi}{dt}$

or $d\phi = MdI = 2.5\ (40 - 0) = 100$ Wb

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26. (d) : Here, $H = B = 0.4 \times 10^{-4}$ T, $l = 0.8$ m
$\upsilon = 120$ rpm $= 2$ rps
Emf induced across the ends of each spoke

$$\varepsilon = \frac{1}{2}B\omega l^2 = \frac{1}{2}B(2\pi\upsilon)l^2 \qquad (\because\ \omega = 2\pi\upsilon)$$

$$= B\pi\upsilon l^2$$

$$\therefore \quad \varepsilon = 0.4 \times 10^{-4} \times \pi \times 2 \times (0.8)^2$$
$$= 1.61 \times 10^{-4}\ \text{V}$$

Note : Number of spokes is not relevant because the emfs across the spoke area is parallel.

27. (c) : The emf developed between the ends of the conductor is

$$\varepsilon = \frac{1}{2}\omega Bl^2 = \frac{1}{2} \times 5 \times 0.2 \times 10^{-4} \times (1)^2$$

$$= 5 \times 10^{-5}\ \text{V} = 50 \times 10^{-6}\ \text{V} = 50\ \mu\text{V}$$

28. (d) : Let a current I_1 flows through the outer circular coil of radius R_1.
The magnetic field at the centre of the coil is

$$B_1 = \frac{\mu_0 I_1}{2R_1}$$

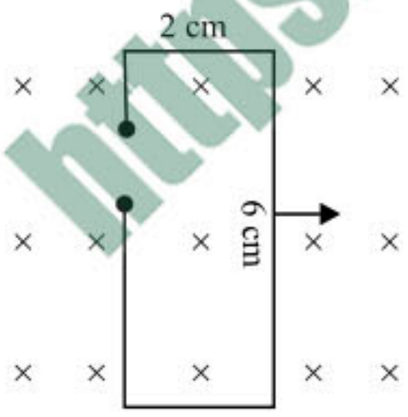
As the inner coil of radius R_2 placed co-axially has small radius ($R_2 < R_1$), therefore B_1 may be taken constant over its cross-sectional area.
Hence, flux associated with the inner coil is

$$\phi_2 = B_1 \pi R_2^2 = \frac{\mu_0 I_1}{2R_1}\pi R_2^2$$

As $$M = \frac{\phi_2}{I_1} = \frac{\mu_0 \pi R_2^2}{2R_1}$$

$$\therefore \quad M \propto \frac{R_2^2}{R_1}$$

29. (b) : Here, $l = 6$ cm $= 6 \times 10^{-2}$ m



$B = 0.4$ T,
$v = 2$ cm s^{-1} $= 2 \times 10^{-2}$ m s^{-1}
Voltage developed is

$$\varepsilon = Blv = 0.4 \times 6 \times 10^{-2} \times 2 \times 10^{-2}$$
$$= 4.8 \times 10^{-4}\ \text{V}$$

30. (c) : Here, $A = 4$ cm^2 $= 4 \times 10^{-4}$ m^2, $N = 20$
Final flux, $\phi_f = 0$
(when the coil is removed from the field)
$q = 7.5$ mC $= 7.5 \times 10^{-3}$ C, $R = 0.8\ \Omega$

As $$I = \frac{\varepsilon}{R} = \frac{-N(d\phi/dt)}{R}$$

$$I\,dt = -\frac{N}{R}d\phi$$

Also charge,

$$q = \int I\,dt = \int_{\phi_i}^{\phi_f} -\frac{N}{R}d\phi = -\frac{N}{R}(\phi_f - \phi_i) = \frac{N}{R}(\phi_i - \phi_f)$$

$$q = \frac{N}{R}\phi_i$$

Now, initial flux per turn when coil is normal to the field,
$\phi_i = BA$

$$\therefore \quad q = \frac{NBA}{R}$$

or $$B = \frac{qR}{NA} = \frac{7.5 \times 10^{-3} \times 0.8}{20 \times 4 \times 10^{-4}} = 0.75\ \text{T}$$

31. (b) : Let $\vec{E}$ be the electric field intensity at a point on the circumference of the ring. Then, the emf induced $\varepsilon = \oint \vec{E} \cdot d\vec{l}$ where $d\vec{l}$ is a length element of the ring. Since $|\vec{E}|$ is constant and $\vec{E} \,||\, d\vec{l}$,

$$\varepsilon = E(2\pi r) \qquad \ldots(i)$$

Also, the induced emf is

$$\varepsilon = \frac{d\phi}{dt} = \pi r^2 \frac{dB}{dt} = \pi r^2 x \qquad \ldots(ii)$$

Equating (i) and (ii), we get

$$E = \frac{rx}{2}$$

32. (b) : Here, $l = 20$ cm $= 20 \times 10^{-2}$ m,
$A = 20$ cm^2 $= 20 \times 10^{-4}$ m^2
$N = 400$, $I_1 = 2$ A, $I_2 = 0$, $dt = 10^{-3}$ s

As $$\varepsilon = \frac{d\phi}{dt} = \frac{d(BAN)}{dt}$$

$$= \frac{\mu_0 N\,dI\,AN}{l\,dt} \qquad \left(\because\ B = \frac{\mu_0 NI}{l}\right)$$

$$= \frac{\mu_0 N(I_1 - I_2)AN}{l\,dt}$$

$$= \frac{4\pi \times 10^{-7} \times (400)^2 \times 2 \times 20 \times 10^{-4}}{20 \times 10^{-2} \times 10^{-3}} = 4\ \text{V}$$

33. (b) : Length of the rod between the axis of rotation and one end of the rod $= \frac{l}{2}$

Area swept out in one rotation

$$= \pi\left(\frac{l}{2}\right)^2 = \left(\frac{\pi l^2}{4}\right)$$

Angular velocity $= \omega$ rad s^{-1}

Frequency of revolution $= \frac{\omega}{2\pi}$

Area swept out per second

$$= \frac{\pi l^2}{4}\left(\frac{\omega}{2\pi}\right) = \frac{l^2\omega}{8}$$

Magnetic induction $= B$

Rate of change of magnetic flux $= \left(\frac{Bl^2\omega}{8}\right)$

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Magnitude of induced emf $= \frac{Bl^2\omega}{8}$

Magnitude of induced emf between the axis and the other end is also $\left(\frac{Bl^2\omega}{8}\right)$.

These two emf's are in opposite directions. Hence, the potential difference between the two ends of the rod is zero.

34. (c) : Given, $\phi = (2t^2 + 4t + 6)$ mWb

As, $\varepsilon = \frac{d\phi}{dt}$

$= \frac{d}{dt}(2t^2 + 4t + 6) \times 10^{-3}$ Wb s^{-1}

$= (4t + 4) \times 10^{-3}$ V

At $t = 4$ s

$\varepsilon = (4 \times 4 + 4) \times 10^{-3}$ V

$= 20 \times 10^{-3}$ V $= 0.02$ V

35. (b) : Here, $l = 2$ m, diameter $= 2$ cm

$\therefore$ radius, $r = \frac{2}{2} = 1$ cm $= 1 \times 10^{-2}$ m

$N_1 = 2000$, $N_2 = 1000$

Area $= \pi r^2 = \pi \times (1 \times 10^{-2})^2$

$= 3.14 \times 10^{-4}$ m^2

Mutual inductance, $M = \frac{\mu_0 N_1 N_2 A}{l}$

$= \frac{4\pi \times 10^{-7} \times 2000 \times 1000 \times 3.14 \times 10^{-4}}{2} = 3.9 \times 10^{-4}$ H

36. (d) : Here, current $I = \frac{V}{R} = \frac{10}{5} = 2$ A

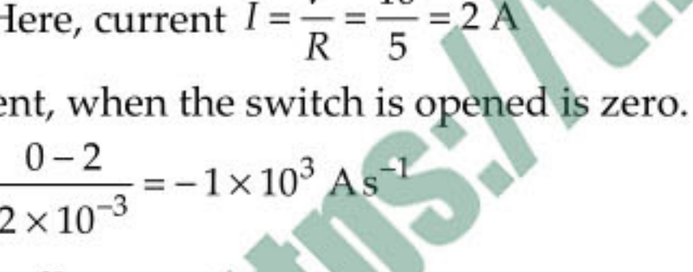
Final current, when the switch is opened is zero.

$\therefore \quad \frac{dI}{dt} = \frac{0 - 2}{2 \times 10^{-3}} = -1 \times 10^3$ A s^{-1}

As $\varepsilon = -L\frac{dI}{dt}$

$= -10\,(-1 \times 10^3) = 10^4$ V

37. (a) : Due to change in the shape of the loop, the magnetic flux linked with the loop increases. Hence, current is induced in the loop in such a direction that it opposes the increases in flux. Therefore, induced current flows in the anticlockwise direction.



38. (d) : No change in flux, hence no force required.

39. (b) : $\phi = B\frac{\pi r^2}{2}\cos\omega t$

$\therefore \quad \varepsilon = -\frac{d\phi}{dt} = \frac{1}{2}B\pi r^2 \omega \sin\omega t$

$\therefore \quad P = \frac{\varepsilon^2}{R} = \frac{B^2\pi^2 r^4 \omega^2 \sin^2\omega t}{4R}$

$\therefore \quad < P > = \frac{(B\pi r^2\omega)^2}{8R} \qquad (\because \ < \sin^2\omega t > = \frac{1}{2})$

40. (a) : Here, $N = 400$, $L = 10$ mH $= 10 \times 10^{-3}$ H

$I = 2$ mA $= 2 \times 10^{-3}$ A

Total magnetic flux linked with the coil,

$\phi = NLI = 400 \times (10 \times 10^{-3}) \times 2 \times 10^{-3} = 8 \times 10^{-3}$ Wb

Magnetic flux through the cross-section of the coil = Magnetic flux linked with each turn

$= \frac{\phi}{N} = \frac{8 \times 10^{-3}}{200} = 4 \times 10^{-5}$ Wb

41. (b)

42. (c) : The energy stored in the inductor is

$U = \frac{1}{2}LI^2$

The energy stored in the inductor per second is

$\frac{dU}{dt} = LI\frac{dI}{dt}$

$= (200 \times 10^{-3}\text{H})(1\text{ A})(0\,5\text{ As}^{-1}) = 0.1\text{ J s}^{-1}$

43. (d) : Current through A, $I = 3.0$ A

Magnetic flux linked with B,

$\phi = 600 \times 9.0 \times 10^{-5}$ Wb

From, $\phi = MI$

Mutual Inductance,

$M = \frac{\phi}{I} = \frac{600 \times 9.0 \times 10^{-5}}{3.0} = 1.8 \times 10^{-2}$H

44. (a) : Here, $r = 0.2$ m, $B = \frac{1}{\pi}$ Wb m^{-2},

$\theta = 60°$

$\therefore$ Magnetic flux,

$\phi = BA\cos\theta = B(\pi r^2)\cos\theta$

$= \frac{1}{\pi}\pi\,(0.2)^2\cos 60° = 0.02$ Wb

45. (c) : Mutual inductance of the system,

$M = \mu_0 n_1 n_2 A_{2l}$

where A_2 is the area of inner solenoid.

$n_1 = 10$ cm$^{-1} = 1000$ m^{-1}

$n_2 = 40$ cm$^{-1} = 4000$ m^{-1}

$l = 30$ cm $= 30 \times 10^{-2}$ m

$A_2 = 20$ cm$^2 = 20 \times 10^{-4}$ m^2

$\therefore \quad M = 4\pi \times 10^{-7} \times 1000 \times 4000 \times 20 \times 10^{-4} \times 30 \times 10^{-2}$

$= 301.44 \times 10^{-5}$ H $= 3$ mH

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Alternating Currents

Alternating Current

It is that current which changes continuously in magnitude and periodically in direction. It can be represented by a sine curve or a cosine curve

$$I = I_0 \sin \omega t \quad \text{or} \quad I = I_0 \cos \omega t$$

Here, I_0 is peak value of current and is known as amplitude of ac, I is instantaneous value of alternating current. $\omega = 2\pi/T = 2\pi\upsilon$ where T is period of ac and υ is frequency of ac

Mean or average value of alternating current or voltage over one complete cycle

The mean or average value of alternating current or voltage over one complete cycle is zero.

$$I_m \text{ or } \bar{I} \text{ or } I_{av} = \frac{\int_0^T I_0 \sin \omega t \, dt}{\int_0^T dt} = 0$$

$$V_m \text{ or } \bar{V} \text{ or } V_{av} = \frac{\int_0^T V_0 \sin \omega t \, dt}{\int_0^T dt} = 0$$

Average value of alternating current for first half cycle is

$$I_{av} = \frac{\int_0^{T/2} I_0 \sin \omega t \, dt}{\int_0^{T/2} dt} = \frac{2I_0}{\pi} = 0.637 I_0$$

Similarly, for alternating voltage, the average value over first half cycle is

$$V_{av} = \frac{\int_0^{T/2} V_0 \sin \omega t dt}{\int_0^{T/2} dt} = \frac{2V_0}{\pi} = 0.637 V_0$$

Average value of alternating current for second half cycle is

$$I_{av} = \frac{\int_{T/2}^{T} I_0 \sin \omega t dt}{\int_{T/2}^{T} dt} = -\frac{2I_0}{\pi} = -0.637\, I_0$$

Similarly, for alternating voltage, the average value over second half cycle is

$$V_{av} = \frac{\int_{T/2}^{T} V_0 \sin \omega t dt}{\int_{T/2}^{T} dt} = -\frac{2V_0}{\pi} = -0.637\, V_0$$

The average value of alternating current (or voltage) during the first and second half cycles are equal but opposite in sign *i.e.* they are alternately positive and negative so that the average over one cycle is zero.

Mean value or average value of alternating current over any half cycle

It is that value of steady current, which would send the same amount of charge through a circuit in the time of half cycle *i.e.* $T/2$ as is sent by ac through the same circuit in the same time.

$$I_{av} = \frac{2I_0}{\pi} = 0.637 I_0$$

Similarly, for alternating voltage

$$I_{av} = \frac{2I_0}{\pi} = 0.637 I_0$$

Root mean square (rms) value of alternating current

It is defined as that value of steady current, which would generate the same amount of heat in a given resistance in a given time, as is done by the alternating current, when passed through the same resistance for the same time. The rms value of ac is also known as effective value or virtual value of ac It is represented by I_{rms}, I_{eff}, or I_v.

$$I_{rms} \text{ or } I_v = \frac{I_0}{\sqrt{2}} = 0.707 I_0$$

Similarly, for alternating voltage

$$V_{rms} = \frac{V_0}{\sqrt{2}} = 0.707\, V_0$$

All ac instruments measure rms value of ac.

Form factor

Form factor is ratio of rms value to average value of alternating current or voltage.

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$$\text{Form factor} = \frac{I_{rms}}{I_{av}} = \frac{I_0/\sqrt{2}}{2I_0/\pi} = \frac{\pi}{2\sqrt{2}} = 1.11$$

AC Circuit Containing Pure Resistance Only

Let $V = V_0 \sin\omega t$

Then, $I = \frac{V}{R} = \frac{V_0}{R} \sin \omega t = I_0 \sin \omega t$

Here the alternating voltage is in phase with current, when ac flows through a resistor.

AC Circuit Containing Pure Inductor Only

Let $V = V_0 \sin\omega t$

Then, $I = I_0 \sin\left(\omega t - \frac{\pi}{2}\right)$

where $I_0 = \frac{V_0}{\omega L}$

Thus, the alternating current lags behind the alternating voltage by a phase angle of $\frac{\pi}{2}$ when ac flows through an inductor.

Inductive reactance

It is the opposition offered by the inductor to the flow of alternating current through it.

$X_L = \omega L = 2\pi\upsilon L$

The inductive reactance is zero for dc ($\upsilon = 0$) and has a finite value for ac

AC Circuit Containing Pure Capacitor Only

Let $V = V_0 \sin\omega t$

$I = I_0 \sin\left(\omega t + \frac{\pi}{2}\right)$

where $I_0 = (\omega C)V_0$.

Thus, the alternating current leads the voltage by a phase angle of $\frac{\pi}{2}$, when ac flows through a capacitor.

Capacitive reactance

It is the opposition offered by the capacitor to the flow of alternating current through it.

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi\upsilon C}$$

The capacitive reactance is infinite for dc ($\upsilon = 0$) and has a finite value for ac

Series *LCR* Circuit

Let $V = V_0 \sin\omega t$

Then, $I = I_0 \sin(\omega t - \phi)$

where $I_0 = \frac{V_0}{Z}$

Here Z is the impedance of the series LCR circuit.

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

The alternating current lags behind the voltage by a phase angle ϕ

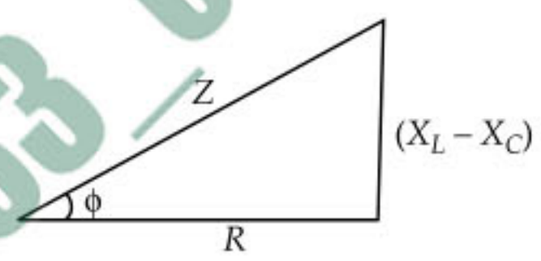
$$\tan\phi = \frac{X_L - X_C}{R}$$

When $X_L > X_C$, $\tan\phi$ is positive. Therefore, ϕ is positive. Hence current lags behind the voltage by a phase angle ϕ. The ac circuit is inductance dominated circuit.

When $X_L < X_C$, $\tan\phi$ is negative. Therefore, ϕ is negative. Hence current leads the voltage by a phase angle ϕ. The ac circuit is capacitance dominated circuit.

Impedance triangle

It is a right angled triangle, whose base represents ohmic resistance (R), perpendicular represents reactance ($X_L - X_C$) and hypotenuse represents impedance (Z) of the series LCR circuit as shown in figure.



Impedance of circuit

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Admittance

The reciprocal of the impedance of an ac circuit is known as admittance. It is represented by Y.

$$\therefore \quad \text{Admittance} = \frac{1}{\text{Impedance}} \quad \text{or} \quad Y = \frac{1}{Z}$$

The unit of admittance is $(\text{ohm})^{-1}$ or siemen.

Susceptance

The reciprocal of the reactance of an ac circuit is known as susceptance. It is represented by S.

$$\therefore \quad \text{Susceptance} = \frac{1}{\text{Reactance}}$$

The unit of susceptance is $(\text{ohm})^{-1}$ or siemen.

- $\text{Inductive susceptance} = \frac{1}{\text{Inductive reactance}}$

  or $S_L = \frac{1}{X_L} = \frac{1}{\omega L}$

- $\text{Capacitive susceptance} = \frac{1}{\text{Capacitive reactance}}$

  or $S_C = \frac{1}{X_C} = \frac{1}{1/\omega C} = \omega C$

Resonant Series *LCR* Circuit

When the frequency of ac supply is such that the inductive reactance and capacitive reactance become equal ($X_L = X_C$), the impedance of the series LCR circuit is equal to the ohmic resistance in the circuit. As such, the current in the circuit becomes maximum. Such a series LCR circuit

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is known as resonant series *LCR* circuit and the frequency of the ac supply is known as resonant frequency (υ_r). The resonant frequency is

$$\upsilon_r = \frac{1}{2\pi\sqrt{LC}} \quad \text{or} \quad \omega_r = \frac{1}{\sqrt{LC}}$$

The series resonance circuit is known as acceptor circuit. It is used in radio and TV receivers sets for tuning a particular radio station/TV channel.

Resonance phenomenon is exhibited by a circuit only if both *L* and *C* are present in the circuit. Then only voltages across *L* and *C* cancel each other. We cannot have resonance in a *RL* or *RC* circuit.

Quality Factor

It is a measure of sharpness of resonance. It is defined as the ratio of reactance of either the inductance or capacitance at the resonant angular frequency to the total resistance of the circuit.

$$Q = \frac{X_L}{R} = \frac{\omega_r L}{R}$$

$$Q = \frac{X_C}{R} = \frac{1}{\omega_r CR}$$

$$\therefore \quad Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

Quality factor is also expressed in terms of bandwidth

$$Q = \frac{\text{Resonant frequency}}{\text{Bandwidth}}$$

Power in an AC Circuit

In an ac circuit we may define three types of power.

- Instantaneous power
- Average power
- Apparent power

Instantaneous power : The power in the ac circuit at any instant of time is known as instantaneous power. It is equal to the product of values of alternating voltage and alternating current at that time.

Average power (P_{av}) : The power averaged over one full cycle of ac is known as average power. It is also known as true power.

$$P_{av} = V_{rms}\, I_{rms} \cos\phi = \frac{V_0 I_0}{2}\cos\phi$$

Apparent power : The product of virtual voltage (V_{rms}) and virtual current (I_{rms}) in the circuit is known as virtual power.

$$P_v = V_{rms}\, I_{rms} = \frac{V_0 I_0}{2}$$

Power Factor

It is defined as the ratio of true power to apparent power of an ac circuit

$$\cos\phi = \frac{\text{True power}}{\text{Apparent power}}$$

Power factor is also defined as the ratio of the resistance to the impedance of an ac circuit

$$\cos\phi = \frac{R}{Z}$$

It is unitless and dimensionless quantity.

In pure resistive circuit,

$$\phi = 0°;\ \cos\phi = 1.$$

In pure inductive or capacitive circuit

$$\phi = \frac{\pi}{2};\ \cos\phi = 0.$$

In *RL* circuit,

$$Z = \sqrt{R^2 + X_L^2} \text{ and } \cos\phi = \frac{R}{Z}$$

In *RC* circuit,

$$Z = \sqrt{R^2 + X_C^2} \text{ and } \cos\phi = \frac{R}{Z}$$

In series LCR circuit,

$$Z = \sqrt{R^2 + (X_L - X_C)^2} \text{ and } \cos\phi = \frac{R}{Z}$$

At resonance, $X_L = X_C$

$\therefore \quad Z = R$ and $\phi = 0°$

$\cos\phi = 1$

Wattless Current

The average power associated over a complete cycle with a pure inductor or pure capacitor is zero, even though a current is flowing through them. This current is known as the wattless current or idle current.

LC-Oscillations

When a charged capacitor discharges through an inductor, *LC*-oscillations are produced. The frequency of the oscillations is given by

$$\upsilon = \frac{1}{2\pi\sqrt{LC}}$$

Transformer

It is a device used for converting a low alternating voltage to a high alternating voltage and vice versa. It is based on phenomenon of mutual induction.

For an ideal transformer, $\frac{V_S}{V_P} = \frac{I_P}{I_S} = \frac{N_S}{N_P} = K$

where *K* is called transformation ratio.

For a step-up transformer, $K > 1$ *i.e.* $V_S > V_P$, $I_S < I_P$ and $N_S > N_P$.

For a step-down transformer $K < 1$ *i.e.* $V_S < V_P$, $I_S > I_P$ and $N_S < N_P$.

Efficiency of a transformer,

$$\eta = \frac{\text{Output power}}{\text{Input power}} = \frac{V_S I_S}{V_P I_P}$$

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EXAM DRILL

1. In a series resonant *LCR* circuit, the voltage across *R* is 100 V and $R = 1\ k\Omega$ with $C = 2\ \mu F$. The resonant frequency ω is 200 rad s^{-1}. At resonance, the voltage across *L* is

(a) 4×10^{-3} V (b) 2.5×10^{-2} V
(c) 40 V (d) 250 V

2. An alternating voltage $V = 200\sqrt{2}\sin(100t)$V is connected to a 1 μF capacitor through an ac ammeter. The reading of ammeter is

(a) 10 mA (b) 20 mA
(c) 40 mA (d) 80 mA

3. The instantaneous values of current and voltage in an ac circuit are given by

$I = 6\sin\left(100\pi t + \frac{\pi}{4}\right)$, $V = 5\sin\left(100\pi t - \frac{\pi}{4}\right)$, then

(a) current leads the voltage by 45°
(b) voltage leads the current by 90°
(c) current leads the voltage by 90°
(d) voltage leads the current by 45°

4. In a series *LCR* circuit, the potential difference between the terminals of the inductance is 60 V, between the terminals of the capacitor is 30 V and that between the terminals of resistance is 40 V. The supply voltage will be equal to

(a) 130 V (b) 10 V
(c) 50 V (d) 70 V

5. A resistor of 500 Ω, an inductance of 0.5 H are in series with an ac which is given by $V = 100\sqrt{2}\sin(1000t)$. The power factor of the combination is

(a) $\frac{1}{\sqrt{2}}$ (b) $\frac{1}{\sqrt{3}}$
(c) 0.5 (d) 0.6

6. A transformer is used to light a 100 W and 110 V lamp from a 220 V mains. If the mains current is 0.5 A, the efficiency of the transformer is approximately

(a) 50% (b) 90%
(c) 10% (d) 30%

7. A pure inductor of 25 mH is connected to an ac source of 220 V. Given the frequency of the source as 50 Hz, the rms current in the circuit is

(a) 7 A (b) 14 A
(c) 28 A (d) 42 A

8. An electron is moving on a circle of radius 0.5 Å with a frequency of 5×10^{16} Hz in anti-clockwise direction. The equivalent loop-current is

(a) 4.0 mA (clockwise)
(b) 4.0 mA (anti-clockwise)
(c) 8.0 mA (clockwise)
(d) 8.0 mA (anti-clockwise)

9. If $V = 100\sin(100t)$ V and $I = 100\sin\left(100t + \frac{\pi}{3}\right)$ mA are the instantaneous values of voltage and current, then the rms values of voltage and current are respectively

(a) 70.7 V, 70.7 mA (b) 70.7 V, 70.7 A
(c) 141.4 V, 141.4 mA (d) 100 V, 100 mA

10. A 0.1 m long conductor carrying a current of 50 A is held perpendicular to a magnetic field of 1.25 mT. The mechanical power required to move the conductor with a speed of 1 m s^{-1} is

(a) 62.5 mW (b) 625 mW
(c) 6.25 mW (d) 12.5 mW

11. In an ac circuit, the current is $I = 5\sin\left(100t - \frac{\pi}{2}\right)$A and the potential difference is $V = 200\sin(100t)$ V. Then the power consumed is

(a) 200 W (b) 500 W (c) 1000 W (d) zero

12. A coil has resistance 30 Ω and inductive reactance 20 Ω at 50 Hz frequency. If an ac source of 200 V, 100 Hz is connected across the coil, the current in the coil will be

(a) 4.0 A (b) 8.0 A
(c) $\frac{20}{\sqrt{13}}$ A (d) 2.0 A

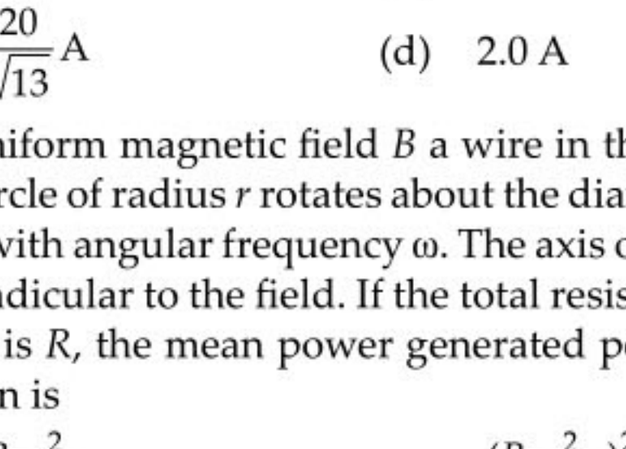
13. In a uniform magnetic field *B* a wire in the form of a semicircle of radius *r* rotates about the diameter of the circle with angular frequency ω. The axis of rotation is perpendicular to the field. If the total resistance of the circuit is *R*, the mean power generated per period of rotation is

(a) $\frac{B\pi r^2\omega}{2R}$ (b) $\frac{(B\pi r^2\omega)^2}{8R}$
(c) $\frac{(B\pi r\omega)^2}{2R}$ (d) $\frac{(B\pi r\omega^2)^2}{8R}$

14. A fully charged capacitor *C* with initial charge q_0 is connected to a coil of self inductance *L* at $t = 0$. The time at which the energy is stored equally between the electric and the magnetic field is

(a) $\frac{\pi}{4}\sqrt{LC}$ (b) $2\pi\sqrt{LC}$ (c) $\sqrt{LC}$ (d) $\pi\sqrt{LC}$

15. The power factor of the circuit as shown In figure is



(a) 0.2 (b) 0.4
(c) 0.8 (d) 0.6

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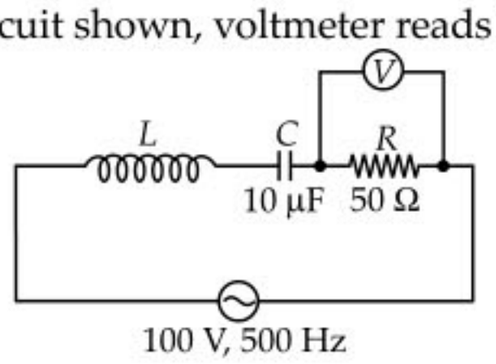
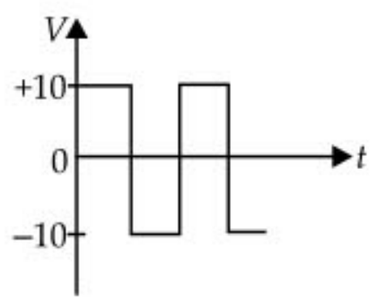
16. If in the circuit shown, voltmeter reads 100 V then L is



(a) 0.1 H (b) 0.2 H
(c) 0.02 H (d) 0.01 H

17. The number of turns in primary and secondary coils of a transformer is 50 and 200. If the current in the primary coil is 4 A, then the current in the secondary coil is
(a) 1 A (b) 2 A
(c) 4 A (d) 5 A

18. The rms voltage of the waveform shown is



(a) 10 V
(b) 7 V
(c) 6.37 V
(d) 20 V

19. An ac voltage is applied to a resistance R and an inductor L in series. If R and the inductive reactance are both equal to 3 Ω, the phase difference between the applied voltage and the current in the circuit is
(a) $\frac{\pi}{6}$ (b) $\frac{\pi}{4}$
(c) $\frac{\pi}{2}$ (d) zero

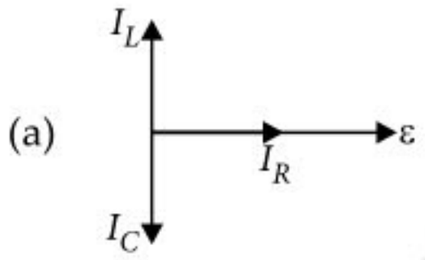
20. Series AC circuit has inductance L, resistance R and angular frequency ω. The quality factor, Q is
(a) $\left(\frac{\omega L}{R}\right)^2$ (b) $\frac{\omega L}{R}$
(c) $\frac{R}{\omega L}$ (d) $\left(\frac{R}{\omega L}\right)^2$

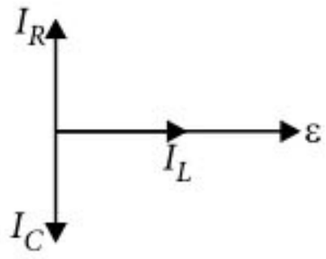
21. A transformer is having 2100 turns in primary and 4200 turns in secondary. An ac source of 120 V, 10 A is connected to its primary. The secondary voltage and current are
(a) 240 V, 5 A (b) 120 V, 10 A
(c) 240 V, 10 A (d) 120 V, 20 A

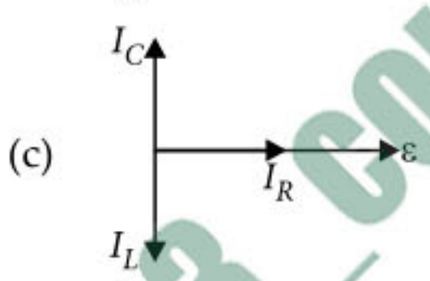
22. A 4 μF capacitor is charged by a 200 V supply. It is then disconnected from the supply and is connected to another uncharged 2 μF capacitor.How much electrostatic energy of the first capacitor is dissipated in the form of heat and electromagnetic radiation?
(a) 2.67×10^{-2} J (b) 2.67×10^{-4} J
(c) 3.67×10^{-2} J (d) 3.67×10^{-4} J

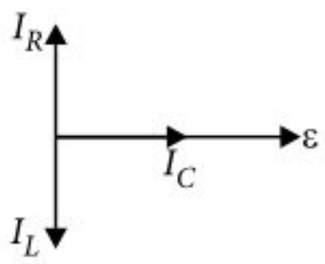
23. In a LCR ac circuit, potential difference between the terminals of the inductance is 60 V, between the terminals of the capacitor is 30 V and that between the terminals of resistance is 40 V. The supply voltage will be
(a) 25 V (b) 50 V
(c) 100 V (d) 200 V

24. An alternating emf is applied across a parallel combination of a resistance R, capacitance C and an inductance L. If I_R, I_L and I_C are the currents through R, L and C respectively, then the diagram which correctly represents the phase relationship among I_R, I_L, I_C and source emf ε, is given by

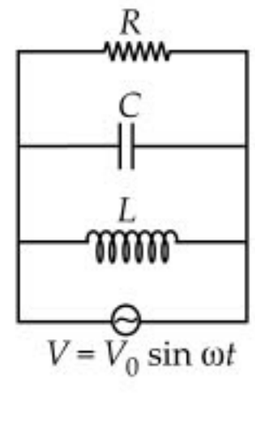
(a) 

(b) 

(c) 

(d) 

25. In the circuit shown in figure $X_L = \frac{X_C}{2} = R$, the peak value current I_0 is



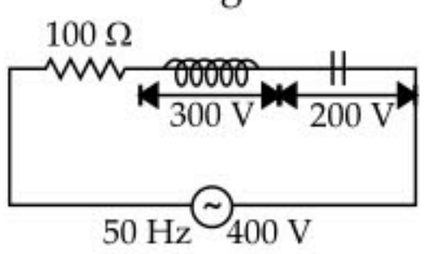
(a) $\frac{\sqrt{5}V_0}{2R}$ (b) $\frac{V_0}{2\sqrt{2}R}$
(c) $\frac{V_0}{2R}$ (d) $\frac{V_0}{2\sqrt{3}R}$

26. A resistor of 500 Ω, an inductance of 0.5 H are in series with an ac which is given by $V = \sin(1000t)$. The power factor of the combination is
(a) $\frac{1}{\sqrt{2}}$ (b) $\frac{1}{\sqrt{3}}$
(c) 0.5 (d) 0.6

27. In a series LCR circuit R = 200 Ω and the voltage and the frequency of the main supply is 220 V and 50 Hz respectively. On taking out the capacitance from the circuit the current lags behind the voltage by 30°. On taking out the inductor from the circuit the current leads the voltage by 30°. The power dissipated in the LCR circuit is
(a) 210 W (b) zero W
(c) 242 W (d) 305 W

28. A series resonant LCR circuit has a quality factor (Q-factor) 0.4 and a bandwidth of 1.3 kHz. If R = 2 kΩ, C = 0.1 μF, then the value of inductance is
(a) 0.1 H (b) 0.064 H
(c) 2 H (d) 10 H

29. In the circuit shown in figure current in the circuit is



(a) 1.27 A (b) 2.23 A
(c) 4.26 A (d) 3.87 A

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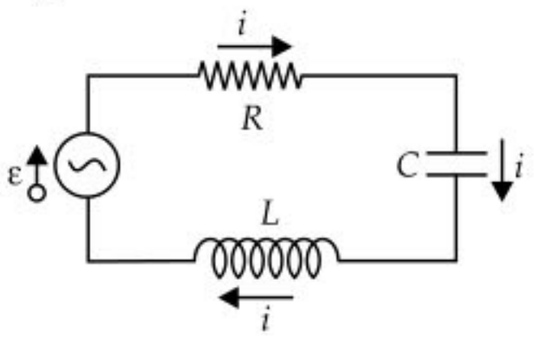
30. A 1.5 μF capacitor is charged of 60 V. The charging battery is then disconnected and a 15 mH coil is connected in series with the capacitor so that *LC* oscillations occur. Assuming that the circuit contains no resistance, the maximum current in this coil shall be close to

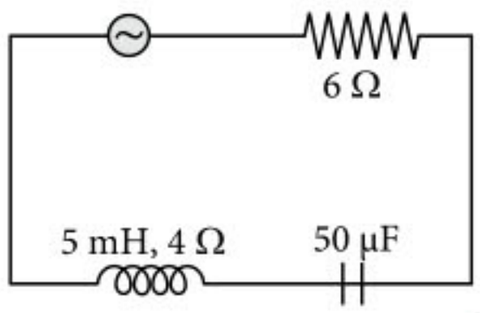
(a) 1.4 A (b) 1.2 A
(c) 0.8 A (d) 0.6 A

31. Figure shows a series *LCR* circuit with $R = 200\ \Omega$, $C = 15.0\ \mu F$ and $L = 230$ mH. If $\varepsilon = 36.0 \sin 120\pi t$, the amplitude I_0 of the current i in the circuit is close to



(a) 109 mA (b) 126 mA
(c) 150 mA (d) 164 mA

32. In the circuit shown, the AC source has voltage $V = 20 \cos(\omega t)$ volt with $\omega = 2000$ rad s^{-1}, the amplitude of the current will be nearest to



(a) 2 A (b) 3.3 A
(c) $2/\sqrt{5}$ A (d) $\sqrt{5}$ A

33. A 150 Ω resistor and an inductance *L* are connected in series to a 200 V, 50 Hz source of negligible impedance. The current comes to 1 A. When the source is changed to 400 V, 100 Hz, the current will be

(a) less than 1 A
(b) 1 A
(c) between 1 A and 2 A
(d) between 2 A and 4 A

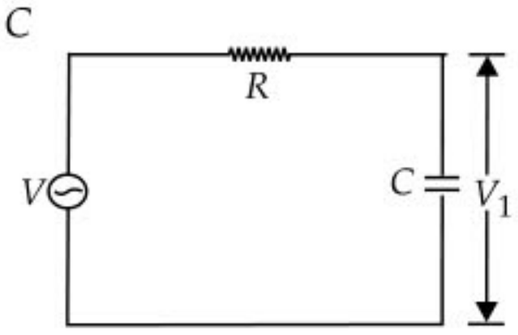
34. A coil has an inductance of 0.7 H and is joined in series with a resistance of 220 Ω. When an alternative emf of 220 V at 50 cps is applied to it, then the wattless component of the current in the circuit is

(a) 5 A (b) 0.5 A
(c) 0.7 A (d) 7 A

35. An inductance of $\frac{200}{\pi}$ mH, a capacitance of $\frac{10^{-3}}{\pi}$ F and a resistance of 10 Ω are connected in series with an ac source of 220 V, 50 Hz. The phase angle of the circuit is

(a) $\frac{\pi}{6}$ (b) $\frac{\pi}{4}$
(c) $\frac{\pi}{2}$ (d) $\frac{\pi}{3}$

36. In the circuit shown, the voltage V_1, across capacitor *C*

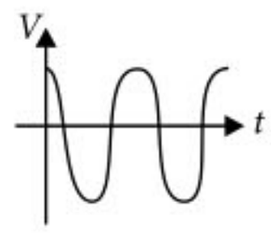


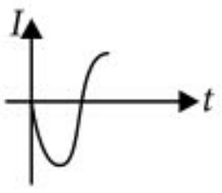
(a) is in phase with the source voltage *V*
(b) leads the source voltage *V* by 90°
(c) leads the source voltage *V* by an angle between 0° and 90°
(d) lags behind the source voltage *V* by an angle between 0° and 90°

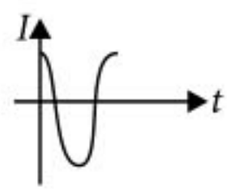
37. A capacitor of capacitance 1 μF is charged to a potential of 1 V. It is connected in parallel to an inductor of inductance 10^{-3} H. The maximum current that will flow in the circuit has the value

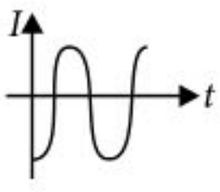
(a) $\sqrt{1000}$ m A (b) 1 m A
(c) 10 m A (d) 1000 m A

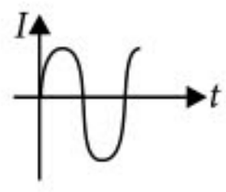
38. The voltage across a pure inductor is represented in figure. Which one of the following curves in the figure will represent the current ?



(a) 

(b) 

(c) 

(d) 

39. What is the value of inductance *L* for which the current is maximum in a series *LCR* circuit with $C = 10\ \mu F$ and $\omega = 1000\ s^{-1}$?

(a) 100 mH
(b) 1 mH
(c) 10 mH
(d) can not be calculated unless *R* is known

40. A step-down transformer is used on a 1000 V line to deliver 20 A at 120 V at the secondary coil. If the efficiency of the transformer is 80%, the current drawn from the line is

(a) 3 A (b) 30 A
(c) 0.3 A (d) 2.4 A

41. A coil of $20 \times 20\ cm^2$ having 30 turns is making 30 rps in a magnetic field of induction 1 T. The peak value of the induced e.m.f. is approximately

(a) 452 V (b) 226 V
(c) 113 V (d) 339 V

42. The rms value of an ac of 50 Hz is 10 A. The time taken by an alternating current in reaching from zero to maximum value and the peak value of current will be

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(a) 2×10^{-2} s and 14.14 A
(b) 1×10^{-2} s and 7.07 A
(c) 5×10^{-3} s and 7.07 A
(d) 5×10^{-3} s and 14.14 A

43. A 16 μF capacitor is charged to a 20 V potential. The battery is then disconnected and a pure 40 mH coil is connected across the capacitor so that LC oscillations are set up. The maximum current in the coil is
(a) 0·2 A (b) 40 mA
(c) 2 A (d) 0·4 A

44. A resistor and a capacitor are connected to an ac supply of 200 V, 50 Hz in series. The current in the circuit is 2 A. If the power consumed in the circuit is 100 W, then the resistance in the circuit is
(a) 25 Ω (b) 20 Ω
(c) $\sqrt{125 \times 75}$ Ω (d) 400 Ω

45. A 750 Hz, 20 V source is connected to a resistance of 100 Ω, an inductance of 0.1803 H and a capacitance of 10 μF all in series. Calculate the time in which the resistance (thermal capacity 2 $J°C^{-1}$) will get heated by 10°C.
(a) 348 s (b) 353 s
(c) 365 s (d) 370 s

DAY 21 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____
(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (d) : Current, $I = \dfrac{V}{Z}$ ...(i)

where, $V = \sqrt{V_R^2 + (V_L - V_C)^2}$ and $Z = \sqrt{R^2 + (X_L - X_C)^2}$

At resonance, $X_L = X_C$, $\therefore \quad Z = R$

and $V_L = V_C$, $\therefore \quad V = V_R$

$\therefore \quad I = \dfrac{V_R}{R} = \dfrac{100}{1 \times 10^3} = 0.1$ A (Using (i)

Voltage across inductance is V_L

$\therefore \quad V_L = V_C = IX_C = \dfrac{I}{\omega C} = \dfrac{0.1}{200 \times 2 \times 10^{-6}} = 250$ V

2. (b) : Comparing $V = 200\sqrt{2}\sin(100t)$ with $V = V_0 \sin\omega t$, we get

$V_0 = 200\sqrt{2}$ and $\omega = 100$

$$X_C = \frac{1}{\omega C} = \frac{1}{100 \times 1 \times 10^{-6}} = 10^4\ \Omega$$

As ac instruments read rms value, the reading of ammeter is

$$I_{rms} = \frac{V_{rms}}{X_C} = \frac{V_0}{\sqrt{2}X_C} \qquad \left(\because V_{rms} = \frac{V_0}{\sqrt{2}}\right)$$

$$= \frac{200\sqrt{2}}{\sqrt{2} \times 10^4} = 2 \times 10^{-2}\ \text{A} = 20\ \text{mA}$$

3. (c) : The phase difference between instantaneous value of I and V is

$$\frac{\pi}{4} - \left(-\frac{\pi}{4}\right) = \frac{\pi}{2}$$

Hence, current leads the voltage by 90°.

4. (c) : In series LCR circuit, $V = \sqrt{V_R^2 + (V_L - V_C)^2}$

$$V = \sqrt{(40)^2 + (60 - 30)^2} = \sqrt{1600 + 900} = \sqrt{2500} = 50\ \text{V}$$

5. (a) : Here, $R = 500\ \Omega$, $L = 0.5$ H

Compare $V = 100\sqrt{2}\sin(1000t)$ with $V = V_0 \sin\omega t$, we get, $\omega = 1000$

The inductive reactance is

$$X_L = \omega L = (1000)(0.5) = 500\ \Omega$$

Impedance of the RL circuit is

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{(500\ \Omega)^2 + (500\ \Omega)^2} = 500\sqrt{2}\ \Omega$$

Power factor, $\cos\phi = \dfrac{R}{Z} = \dfrac{500\ \Omega}{500\sqrt{2}\ \Omega} = \dfrac{1}{\sqrt{2}}$

6. (b) : Given : Output power, $P = 100$ W

Voltage across primary coil, $V_p = 220$ V

Current in the primary coil, $I_p = 0.5$ A

Efficiency of a transformer,

$$\eta = \frac{\text{Output power}}{\text{Input power}} \times 100$$

$$= \frac{P}{V_p I_p} \times 100 = \frac{100}{220 \times 0.5} \times 100 \approx 90\%$$

7. (c) : Here, $L = 25$ mH $= 25 \times 10^{-3}$ H

$\upsilon = 50$ Hz, $V_{rms} = 220$ V

The inductive reactance is

$$X_L = 2\pi\upsilon L = 2 \times \frac{22}{7} \times 50 \times 25 \times 10^{-3}\ \Omega$$

The rms current in the circuit is

$$I_{rms} = \frac{V_{rms}}{X_L} = \frac{220}{2 \times \frac{22}{7} \times 50 \times 25 \times 10^{-3}}$$

$$= \frac{7 \times 1000}{2 \times 5 \times 25}\ \text{A} = 28\ \text{A}$$

8. (c) : Charges crossing a point per second is current *i.e.*, $e \times \upsilon$ (this frequency of rotation is for a given radius).

$\therefore \quad I = 1.6 \times 10^{-19} \times 5 \times 10^{16} = 8 \times 10^{-3}$ A $= 8$ mA

The direction of the current is opposite to the motion of the electron i.e., clockwise.

9. (a) : The instantaneous value of voltage is

$V = 100\sin(100t)$ V ...(i)

Compare it with

$V = V_0 \sin(\omega t)$ V

we get

$V_0 = 100$ V, $\omega = 100$ rad s^{-1}

The rms value of voltage is

$$V_{rms} = \frac{V_0}{\sqrt{2}} = \frac{100}{\sqrt{2}}\ \text{V} = 70.7\ \text{V}$$

The instantaneous value of current is

$$I = 100\sin\left(100t + \frac{\pi}{3}\right)\ \text{mA}$$

Compare it with

$I = I_0 \sin(\omega t + \phi)$

we get

$I_0 = 100$ mA, $\omega = 100$ rad s^{-1}

The rms value of current is

$$I_{rms} = \frac{I_0}{\sqrt{2}} = \frac{100}{\sqrt{2}}\ \text{mA} = 70.7\ \text{mA}$$

10. (c) : Here, $l = 0.1$ m, $v = 1$ m s^{-1}

$I = 50$ A, $B = 1.25$ mT $= 1.25 \times 10^{-3}$ T

The induced emf is, $\varepsilon = Blv$

The mechanical power is

$P = \varepsilon I = BlvI = 1.25 \times 10^{-3} \times 0.1 \times 1 \times 50$

$= 6.25 \times 10^{-3}$ W $= 6.25$ mW

11. (d) : Here, $I = 5\sin\left(100t - \dfrac{\pi}{2}\right)$ A

$V = 200\sin(100t)$ V

$\therefore \quad$ Phase difference between V and I is $\phi = \dfrac{\pi}{2}$

Power consumed, $P = V_{rms}\ I_{rms} \cos\phi$

$= V_{rms}\ I_{rms} \cos 90° =$ zero

12. (a) : Here, $R = 30\ \Omega$, $X_L = 20\ \Omega$, $\upsilon = 50$ Hz

$X_L = \omega L = 2\pi\upsilon L$ or $20 = 2\pi \times 50 \times L$ ...(i)

When $\upsilon' = 100$ Hz, then

$$X'_L = 2\pi \times 100 \times L = 2(2\pi \times 50L)$$

$$= 2 \times 20 = 40\ \Omega \qquad \text{(Using (i))}$$

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Current in the coil is

$$I_{rms} = \frac{V_{rms}}{\sqrt{R^2 + X_L'^2}} = \frac{200}{\sqrt{30^2 + 40^2}} = 4 \text{ A}$$

13. (b) : $\phi = B\frac{\pi r^2}{2}\cos\omega t$

$$\therefore \quad \varepsilon = -\frac{d\phi}{dt} = \frac{1}{2}B\pi r^2 \omega \sin\omega t$$

$$\therefore \quad P = \frac{\varepsilon^2}{R} = \frac{B^2\pi^2 r^4 \omega^2 \sin^2\omega t}{4R}$$

$$\therefore \quad < P >= \frac{(B\pi r^2\omega)^2}{8R} \qquad (\because \ < \sin^2\omega t >= \frac{1}{2})$$

14. (a) : As $\omega^2 = \frac{1}{LC}$ or $\omega = \frac{1}{\sqrt{LC}}$

Maximum energy stored in capacitor $= \frac{1}{2}\frac{Q_0^2}{C}$

Let at an instant t, the energy be stored equally between electric and magnetic field. Then energy stored in electric field at instant t is

$$\frac{1}{2}\frac{Q^2}{C} = \left[\frac{1}{2}\frac{Q_0^2}{C}\right]$$

or $\quad Q^2 = \frac{Q_0^2}{2}$ or $Q = \frac{Q_0}{\sqrt{2}}$ or $Q_0\cos\omega t = \frac{Q_0}{\sqrt{2}}$

or $\quad \omega t = \frac{\pi}{4}$ or $t = \frac{\pi}{4\omega} = \frac{\pi}{4\times(1/\sqrt{LC})} = \frac{\pi\sqrt{LC}}{4}$

15. (c) : Resistance of the circuit,

$R = R_1 + R_2 = 40\ \Omega + 40\ \Omega = 80\ \Omega$

Impedance of the circuit,

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(80)^2 + (100-40)^2}$$

$$= \sqrt{(80)^2 + (60)^2} = 100\ \Omega$$

Power factor, $\cos\phi = \frac{R}{Z} = \frac{80}{100} = 0.8$

16. (d) : This is feasible only at resonance.

$$\therefore \quad 500 = \frac{1}{2\pi\sqrt{LC}} \text{ or } \frac{1}{2\pi\sqrt{L\times 10\times 10^{-6}}} = 500$$

On solving, we get $L = 0.01$ H

17. (a) : Here, $N_p = 50$, $N_s = 200$, $I_p = 4$ A, $I_s = ?$

As $\frac{I_p}{I_s} = \frac{N_s}{N_p}$ or $I_s = \frac{N_p}{N_s}I_p = \frac{50}{200}\times 4\text{ A} = 1\text{ A}$

18. (a) : $V_{rms} = \sqrt{\frac{1}{T}\int_0^T 10^2 dt} = 10$ V

19. (b) : Here, $R = 3\ \Omega$, $X_L = 3\ \Omega$

If ϕ is the phase difference between the applied voltage and the current in the circuit, then

$$\tan\phi = \frac{X_L}{R} = \frac{3}{3} = 1 \text{ or } \phi = \frac{\pi}{4}$$

20. (b) : Quality factor of a series LCR circuit is defined as the ratio of the voltage drop across the inductance (or capacitance) at resonance to the applied voltage, *i.e.*,

$$Q = \frac{\omega L}{R}$$

21. (a) : As $\frac{V_s}{V_p} = \frac{N_s}{N_p}$

$$\therefore \quad V_s = \frac{N_s}{N_p}V_p = \frac{4200}{2100}\times 120 = 240 \text{ V}$$

As $\frac{I_s}{I_p} = \frac{N_p}{N_s}$

$$\therefore \quad I_s = \frac{N_p}{N_s}I_p = \frac{2100}{4200}\times 10 = 5 \text{ A}$$

22. (a) : Here, $C_1 = 4\ \mu\text{F} = 4\times 10^{-6}$ F, $V_1 = 200$ V

Initial electrostatic energy stored in C_1 is

$$U_1 = \frac{1}{2}C_1V_1^2 = \frac{1}{2}\times 4\times 10^{-6}\times 200\times 200$$

$U_1 = 8\times 10^{-2}$ J

When 4 μF capacitor is connected to uncharged capacitor of 2 μF, charge flows and both acquire a common potential which is given by

$$V = \frac{\text{Total charge}}{\text{Total capacity}}\ ;\ V = \frac{C_1V_1}{C_1 + C_2}$$

$$V = \frac{4\times 10^{-6}\times 200}{(4+2)\times 10^{-6}} = \frac{800}{6} \text{ V}$$

$\therefore$ Final electrostatic energy of both capacitors

$$U_2 = \frac{1}{2}(C_1 + C_2)V^2 = \frac{1}{2}\times 6\times 10^{-6}\times\frac{800}{6}\times\frac{800}{6}$$

$$= 5.33\times 10^{-2} \text{ J}$$

$\therefore$ Energy dissipated in the form of heat and electromagnetic radiation is

$U_1 - U_2 = (8\times 10^{-2} - 5.33\times 10^{-2})$ J $= 2.67\times 10^{-2}$ J

23. (b) : Here, $V_L = 60$ V, $V_C = 30$ V, $V_R = 40$ V

The supply voltage of the series LCR circuit is

$$V = \sqrt{V_R^2 + (V_L - V_C)^2}$$

$$= \sqrt{(40\text{ V})^2 + (60\text{ V} - 30\text{ V})^2} = \sqrt{(2500\text{ V})^2} = 50 \text{ V}$$

24. (c) : Current in inductance I_L lags behind the emf in phase by $\pi/2$, current in resistance I_R is in phase with emf, while current in capacitance I_C leads by a phase of $\pi/2$.

25. (a) : $\frac{1}{Z} = \sqrt{\frac{1}{R^2} + \left(\frac{1}{X_C} - \frac{1}{X_L}\right)^2}$

Substituting the given values, we get

$$\frac{1}{Z} = \sqrt{\frac{1}{R^2} + \left(\frac{1}{2R} - \frac{1}{R}\right)^2}$$

$$\frac{1}{Z} = \sqrt{\frac{1}{R^2} + \frac{1}{4R^2}}$$

$$\frac{1}{Z} = \frac{\sqrt{5}}{2R} \quad \text{or} \quad Z = \frac{2R}{\sqrt{5}} \quad \therefore \quad I_0 = \frac{V_0}{Z} = \frac{\sqrt{5}V_0}{2R}$$

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26. (a) : Here, $R = 500\ \Omega$, $L = 0.5$ H

Compare $V = 100\sqrt{2}\sin(1000t)$ with $V = V_0 \sin\omega t$, we get

$\omega = 1000$

The inductive reactance is

$X_L = \omega L = (1000)(0.5) = 500\ \Omega$

Impedance of the RL circuit is

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{(500\ \Omega)^2 + (500\ \Omega)^2} = 500\sqrt{2}\ \Omega$$

Power factor, $\cos\phi = \dfrac{R}{Z} = \dfrac{500\ \Omega}{500\sqrt{2}\ \Omega} = \dfrac{1}{\sqrt{2}}$

27. (c) : Here, $R = 200\ \Omega$, $V_{rms} = 220$ V, $\upsilon = 50$ Hz

When only the capacitance is removed,

$$\tan\phi = \frac{X_L}{R} \text{ or } \tan 30° = \frac{X_L}{R} \text{ or } X_L = \frac{1}{\sqrt{3}}R$$

When only the inductance is removed, $\tan\phi' = \dfrac{X_C}{R}$ or $\tan 30° = \dfrac{X_C}{R}$ or $X_C = \dfrac{1}{\sqrt{3}}R$

As $X_L = X_C$, therefore the given series LCR is in resonance.

$\therefore$ Impedance of the circuit is $Z = R = 200\ \Omega$

The power dissipated in the circuit is

$$P = V_{rms} I_{rms}\cos\phi = \frac{V_{rms}^2}{Z}\cos\phi \quad \left(\because\ I_{rms} = \frac{V_{rms}}{Z}\right)$$

At resonance, power factor $\cos\phi = 1$

$$\therefore\ P = \frac{V_{rms}^2}{Z} = \frac{(220\ \text{V})^2}{(200\ \Omega)} = 242\ \text{W}$$

28. (b) : $Q = \dfrac{1}{R}\sqrt{\dfrac{L}{C}}$ or $\dfrac{L}{C} = (QR)^2$

$\therefore\ L = (0.4 \times 2 \times 10^3)^2 \times 0.1 \times 10^{-6} = 0.064$ H

29. (d) : Current in the circuit is

$$I = \frac{V_R}{R} = \frac{\sqrt{V^2 - (V_L - V_C)^2}}{R}$$

$$= \frac{\sqrt{(400\ \text{V})^2 - (300\ \text{V} - 200\ \text{V})^2}}{100\ \Omega} = 3.87\ \text{A}$$

30. (d) : Here $q_0 = CV = 1.5 \times 10^{-6} \times 60 = 9 \times 10^{-5}$ C

Oscillating charge in LC circuit

$$q = q_0 \sin\left(\omega t + \frac{\pi}{2}\right)$$

$\therefore$ Oscillating current,

$$I = \frac{dq}{dt} = q_0\omega\cos\left(\omega t + \frac{\pi}{2}\right)$$

$\therefore$ Maximum current,

$$I_0 = q_0\omega = \frac{q_0}{\sqrt{LC}} \qquad \left(\because\ \omega = \frac{1}{\sqrt{LC}}\right)$$

$$= \frac{9 \times 10^{-5}}{\sqrt{15 \times 10^{-3} \times 1.5 \times 10^{-6}}} = 0.6\ \text{A}$$

31. (d) : Given $R = 200\ \Omega$, $C = 15.0\ \mu\text{F} = 15 \times 10^{-6}$ F

$L = 230$ mH $= 230 \times 10^{-3}$ H, $\varepsilon = 36.0 \sin 120\pi t$

Compare it with standard equation

$\varepsilon = \varepsilon_0 \sin\omega t$

We get

$\varepsilon_0 = 36.0$, $\omega = 120\pi$

The capacitive reactance is

$$X_C = \frac{1}{\omega C} = \frac{1}{120\pi \times 15 \times 10^{-6}} = 177\ \Omega$$

The inductive reactance is

$X_L = \omega L = 120\pi \times 230 \times 10^{-3} = 87\ \Omega$

Impedance of the series LCR circuit is

$$Z = \sqrt{R^2 + (X_C - X_L)^2} = \sqrt{(200)^2 + (177 - 87)^2} = 219\ \Omega$$

$$\therefore\ I_0 = \frac{\varepsilon_0}{Z} = \frac{36\ \text{V}}{219\ \Omega} = 164\ \text{mA}$$

32. (a) : Total resistance of the circuit

$R = 6 + 4 = 10\ \Omega$

Capacitive reactance

$$X_C = \frac{1}{\omega C} = \frac{1}{2000 \times 50 \times 10^{-6}} = 10\ \Omega$$

Inductive reactance

$X_L = \omega L = 2000 \times 5 \times 10^{-3} = 10\ \Omega$

$$\therefore\ Z = \sqrt{R^2 + (X_L - X_C)^2} = 10\ \Omega$$

Amplitude of current

$$I_0 = \frac{V_0}{Z} = \frac{20}{10} = 2\ \text{A}$$

33. (c) : As $I = \dfrac{200}{\sqrt{R^2 + X_L^2}} = 1, \Rightarrow \sqrt{R^2 + X_L^2} = 200$

or $R^2 + X_L^2 = 40{,}000$

or $(150)^2 + X_L{}^2 = 40{,}000$

or $X_L^2 = 40{,}000 - 22{,}500 = 17{,}500$

Since $\upsilon' = 100$ Hz and $\nu = 50$ Hz,

$\Rightarrow\ \upsilon' = 2\upsilon$

As $X_L = 2\pi\nu L \Rightarrow \dfrac{X'_L}{X_L} = \dfrac{2\pi\nu' L}{2\pi\nu L} = 2$ or $X'_L = 2X_L$

or $X_L'^2 = 4X_L^2 = 4(17500) = 70{,}000$

$$\therefore\ Z' = \sqrt{R^2 + X_L'^2} = \sqrt{(150)^2 + 70{,}000}\ \Omega = 304\ \Omega$$

$$\therefore\ I' = \frac{V'}{Z'} = \frac{400}{304} = 1.3\ \text{A} \qquad [\text{Given } V' = 400\ \text{V}]$$

(between 1 A and 2A)

34. (b) : $\tan\phi = \dfrac{X_L}{R} = \dfrac{\omega L}{R} = \dfrac{2\pi \times 50 \times 0.7}{220} = 1$

$\Rightarrow\ \phi = 45°$ and $Z = \sqrt{R^2 + X_L^2} = \sqrt{220^2 + 220^2} = 220\sqrt{2}\ \Omega$

Wattles component of current $= I_v \sin\phi$

$$= \frac{E_v}{Z}\sin 45° = \frac{220}{220\sqrt{2}} \times \frac{1}{\sqrt{2}} = 0{\cdot}5\ \text{A}$$

35. (b) : Here, $L = \dfrac{200}{\pi}$ mH $= \dfrac{200 \times 10^{-3}}{\pi}$ H $= \dfrac{0.2}{\pi}$ H

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$V_{rms} = 220$ V, $\upsilon = 50$ Hz

The inductive reactance is

$$X_L = \omega L = 2\pi\upsilon L = 2\pi \times 50 \times \frac{0.2}{\pi} = 20\ \Omega$$

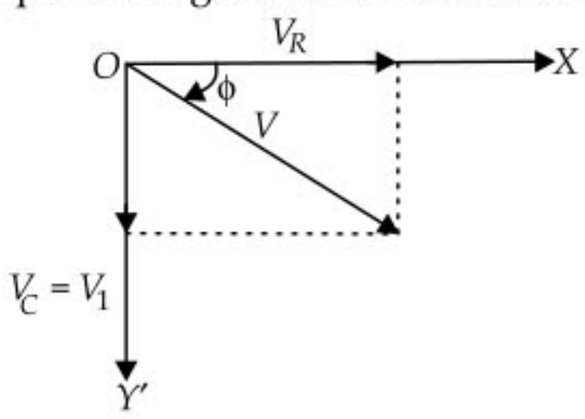
The capacitive reactance is

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi\upsilon C} = \frac{\pi}{2\pi \times 50 \times 10^{-3}} = 10\ \Omega$$

As $\tan\phi = \dfrac{(X_L - X_C)}{R} = \dfrac{20 - 10}{10} = 1$

$\Rightarrow \quad \phi = \dfrac{\pi}{4}$

36. (d) : The phase diagram is as shown in the figure.



37. (a) : Charge on the emf capacitor,

$q_0 = CV = 1 \times 10^{-6} \times 1 = 10^{-6}$ C $= 1\ \mu$C

Here, $q = q_0 \sin\omega t$

$\Rightarrow \quad \dfrac{dq}{dt} = q_0\omega\cos\omega t$

Maximum current $I_0 = \omega q_0$

Now, $\omega = \dfrac{1}{\sqrt{LC}} = \dfrac{1}{\sqrt{10^{-3} \times 10^{-6}}} = \dfrac{1}{\sqrt{10^{-9}}} = (10^9)^{1/2}$

$\therefore \quad I_0 = (10^9)^{1/2} \times (1 \times 10^{-6}) = \sqrt{1000}$ mA

38. (d) : Current lags behind the voltage by $\dfrac{\pi}{2}$.

39. (a) : In resonance condition, maximum current flows in the circuit.

Hence, current in *LCR* series circuit,

$$I = \frac{V}{\sqrt{R^2 + (X_L - X_C)^2}}$$

where V is rms value of voltage, R is resistance, X_L is inductive reactance and X_C is capacitive reactance.

For current to be maximum, denominator should be minimum which can be done, if

$X_L = X_C$

This happens in resonance state of the circuit *ie*, $\omega L = \dfrac{1}{\omega C}$

or $\quad L = \dfrac{1}{\omega^2 C} \qquad ...(i)$

Given, $\omega = 1000\ s^{-1}$, $C = 10\ \mu F = 10 \times 10^{-6}$ F

Hence, $L = \dfrac{1}{(1000)^2 \times 10 \times 10^{-6}} = 0.1$ H $= 100$ mH

40. (a) : Here, $E_p = 1000$ V, $I_s = 20$ A, $E_s = 120$ V

$\eta = 80\%$

As $\quad \eta = \dfrac{E_s I_s}{E_p I_p} \ \therefore \ \dfrac{80}{100} = \dfrac{120 \times 20}{1000 \times I_p}$

$$I_p = \frac{2.4 \times 10}{8} = 3\ \text{A}$$

41. (b) : Here, $A = 20 \times 20\ cm^2 = 20 \times 20 \times 10^{-4}\ m^2$
$= 4 \times 10^{-2}\ m^2$

$n = 30$ rps, $B = 1$ T, $N = 30$ turns

$\varepsilon = NAB\,\omega = NAB\,(2\pi\upsilon)$

$= 30 \times 4 \times 10^{-2} \times 1 \times 2 \times 3.14 \times 30 = 226$ V

42. (d) : Here, $I_v = 10$ A, $\upsilon = 50$ Hz

$I_0 = \sqrt{2}\, I_v = 1{\cdot}414 \times 10 = 14{\cdot}14$ A

Time taken to reach from zero to maximum value

$t = \dfrac{T}{4} = \dfrac{1}{4\upsilon} = \dfrac{1}{4 \times 50}$ s $= \dfrac{1}{200}$ s $= 5 \times 10^{-3}$ s

43. (d) : Energy stored in capacitor $= \dfrac{1}{2} CV^2$

$= \dfrac{1}{2} \times 16 \times 10^{-6} \times (20)^2 = 3{\cdot}2 \times 10^{-3}$ J

Energy supplied to inductor $= \dfrac{1}{2} LI^2 = 3 \cdot 2 \times 10^{-3}$

$\Rightarrow \quad \dfrac{1}{2} \times (40 \times 10^{-3})\, I^2 = 3{\cdot}2 \times 10^{-3}$

$\therefore \quad I^2 = \dfrac{2 \times 3{\cdot}2}{40}$

$I = \dfrac{4}{10} = 0{\cdot}4$ A

44. (a) : $P = E_v I_v \cos\phi$

$\Rightarrow \quad 100 = 200 \times 2\cos\phi$ or $\cos\phi = \dfrac{100}{400} = \dfrac{1}{4}$

and $Z = \dfrac{E_v}{I_v} = \dfrac{200}{2} = 100$

From $\cos\phi = \dfrac{R}{Z}$, $R = Z\cos\phi = 100 \times \dfrac{1}{4} = 25\Omega$

45. (a) : As,

$X_L = \omega L = 2\pi\upsilon L = 2\pi \times 750 \times 0.1803 = 849.2\ \Omega$

and $X_C = \dfrac{1}{\omega C} = \dfrac{1}{2\pi\upsilon C} = \dfrac{1}{2\pi \times 750 \times 10^{-5}} = 21.2\ \Omega$

So, $\quad X = X_L - X_C = 849.2 - 21.2 = 828\ \Omega$

Hence, $Z = \sqrt{R^2 + X^2} = \sqrt{(100)^2 + (828)^2} = 834\ \Omega$

But as in case of AC,

$$P_{av} = V_{rms} I_{rms} \cos\phi = V_{rms} \times \frac{V_{rms}}{Z} \times \frac{R}{Z}$$

i.e., $\quad P_{av} = \left(\dfrac{V_{rms}}{Z}\right)^2 \times R = \left(\dfrac{20}{834}\right)^2 \times 100 = 0.0575$ W

And as, $U = P \times t = mc\Delta\theta$

$\therefore \quad t = \dfrac{mc \times \Delta\theta}{P} = \dfrac{2 \times 10}{0.0575} = 348$ s

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Electromagnetic Waves

Displacement Current

The displacement current is that current which appears in the region in which the electric field (and hence electric flux) is changing with time. It is given by

$$I_d = \varepsilon_0 \frac{d\phi_E}{dt}$$

where,

$\frac{d\phi_E}{dt}$ = rate of change of electric flux between the plates of capacitor.

In case of a steady electric flux linked with a region, the displacement current is zero.

Consequences of displacement current

- The concept of displacement current has made the laws of electricity and magnetism symmetrical. According to Faraday's law of electromagnetic induction, the magnitude of induced emf is equal to the rate of change of magnetic flux. Now the existence of emf implies that there is electric field. Therefore, we can restate Faraday's law as time varying magnetic field produces an electric field. By symmetry, a time varying electric field should produce magnetic field and this is what displacement current does.
- The symmetry of electricity and magnetism led to the existence of electromagnetic waves.

Electromagnetic waves

The electromagnetic waves consist of sinusoidal variation of electric and magnetic fields at right angles to each other as well as at right angles to the direction of propagation of waves.

Examples of electromagnetic waves are radio waves, infrared waves, X-rays, light etc. The theory of electromagnetic waves was developed in 1864 by Maxwell.

For a plane progressive electromagnetic wave propagating along the +z direction, the electric and magnetic fields can be written as

$$E = E_0 \sin(kz - \omega t)$$
$$B = B_0 \sin(kz - \omega t)$$

In electromagnetic wave, the electric and magnetic fields vary with space and time and have the same frequency and are in the same phase.

The amplitudes of electric and magnetic fields in free space, in electromagnetic waves are related by

$$E_0 = cB_0 \quad \text{or} \quad B_0 = \frac{E_0}{c}$$

The speed of electromagnetic wave in free space is

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

where μ_0 and ε_0 are the permeability and permittivity of free space.

The speed of electromagnetic wave in a medium is

$$v = \frac{1}{\sqrt{\mu\varepsilon}}$$

where μ and ε are permeability and permittivity of the medium

$$v = \frac{1}{\sqrt{\mu_0 \mu_r \varepsilon_0 \varepsilon_r}} = \frac{c}{\sqrt{\mu_r \varepsilon_r}}$$

Production of electromagnetic waves

Maxwell showed that an accelerating charge produces electromagnetic waves. An electric charge oscillating harmonically with frequency υ produces electromagnetic waves of the same frequency υ.

An electric dipole is a basic source of electromagnetic waves.

Hertz was the first to demonstrate the production of electromagnetic waves in the laboratory.

Characteristics of electromagnetic waves

- These are produced due to variation of electric or magnetic fields but they themselves are not charged.
- These are not deflected by electric or magnetic fields.
- They travel with the speed of light c in vacuum.
- They can pass through vacuum as no medium is required for their propagation.
- They are transverse in nature.
- They affect photographic plates.
- Their rest mass is zero. But they possess momentum.
- They can be polarised.

Energy density of electromagnetic waves

Electromagnetic waves carry energy as they travel through space and this energy is equally shared by electric field and magnetic field of electromagnetic wave.

The energy density of the electric field is

$$u_E = \frac{1}{2}\varepsilon_0 E^2$$

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The energy density of magnetic field is

$$u_B = \frac{1}{2}\frac{B^2}{\mu_0}$$

Average energy density of the electric field is

$$< u_E > = \frac{1}{4}\varepsilon_0 E_0^2$$

Average energy density of the magnetic field is

$$< u_B > = \frac{1}{4}\frac{B_0^2}{\mu_0} = \frac{1}{4}\varepsilon_0 E_0^2$$

Average energy density of electromagnetic wave is

$$< u > = \frac{1}{2}\varepsilon_0 E_0^2$$

Intensity of electromagnetic wave

It is defined as energy crossing per unit area per unit time perpendicular to the direction of propagation of electromagnetic wave. The intensity of electromagnetic wave is

$$I = < u > c = \frac{1}{2}\varepsilon_0 E_0^2 c$$

Momentum of electromagnetic wave

An electromagnetic wave carries linear momentum.

Electromagnetic wave strikes the surface at normal incidence and transports a total energy U to the surface in a time t, if the surface absorbs all the incident energy, the total momentum p transported to the surface is

$$p = \frac{U}{c} \text{ (complete absorption)}$$

If the surface is a perfect reflector and incidence is normal then the momentum transported to the surface is

$$p = \frac{2U}{c} \text{ (complete reflection)}$$

Radiation pressure

It is defined as the pressure exerted by the electromagnetic wave on a surface.

If I is the intensity of the incident electromagnetic radiation, then the radiation pressure for normal incidence is

- $P_{\text{radiation}} = \frac{I}{c}$ (perfectly absorbing surface)
- $P_{\text{radiation}} = \frac{2I}{c}$ (perfectly reflecting surface)

Poynting Vector

In electromagnetic wave, the rate of flow of energy perpendicularly through a unit area is described by a vector known as poynting vector.

The poynting vector is

$$\vec{S} = \frac{1}{\mu_0}\left(\vec{E} \times \vec{B}\right)$$

The SI unit of poynting vector is W m^{-2}.

Electromagnetic spectrum

The orderly distribution of electromagnetic radiations according to their wavelength or frequency is known as electromagnetic spectrum.

The different types of electromagnetic waves with their wavelength range, their sources of production and detection as shown in the table.

Type	Wavelength range	Production	Detection
Radio waves	> 0.1 m	Rapid acceleration and decelerations of electrons in aerials	Receiver's aerials
Microwaves	0.1 m to 1 mm	Klystron valve or magnetron valve	Point contact diodes
Infrared	1 mm to 700 nm	Vibration of atoms and molecules	Thermopiles, Bolometer, Infrared photographic film
Visible light	700 nm to 400 nm	Electrons in atoms emit light when they move from one energy level to a lower energy level	The eye, Photocells, Photographic film
Ultraviolet	400 nm to 1 nm	Inner shell electrons in atoms moving from one energy level to a lower level	Photocells, Photographic film
X-rays	1 nm to 10^{-3} nm	X-ray tubes or inner shell electrons	Photographic film, Geiger tubes, Ionization chamber
Gamma rays	< 10^{-3} nm	Radioactive decay of the nucleus	Photographic film, Ionization chamber, Geiger tubes

Uses of Electromagnetic Spectrum

Radio wave: They are used in radio and TV communication system.

Micro wave: They are used in radar and TV communication.

Infrared radiations are used

- in green houses to keep the plants warm.
- in revealing the secret writings on the ancient walls.
- for looking through haze, fog and mist during war time, as these radiations can pass through them.

Ultraviolet radiations are used

- in preserving the food stuffs.
- in the detection of invisible writing, forgetd documents, finger prints in forensic laboratory.
- for knowing the structure of the molecules and arrangement of electrons in the external shells.

X-rays have many applications : These rays provide us valuable information

- about the structure of atomic nuclei.
- in the study of crystal structure.
- in the fracture of bones etc.

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EXAM DRILL

1. Which of the following statements is false for the properties of electromagnetic waves ?
(a) Both electric and magnetic field vectors attain the maxima and minima at the same place and same time.
(b) The energy in electromagnetic wave is divided equally between electric and magnetic vectors.
(c) Both electric and magnetic field vectors are parallel to each other and perpendicular to the direction of propagation of wave.
(d) These waves do not require any material medium for propagation.

2. The rms value of the electric field of the light coming from the sun is 720 N C^{-1}. The average total energy density of the electromagnetic wave is
(a) 3.3×10^{-3} J m^{-3} (b) 4.58×10^{-6} J m^{-3}
(c) 6.37×10^{-9} J m^{-3} (d) 81.35×10^{-12} J m^{-3}

3. The magnetic field in a plane electromagnetic wave is given by
$B_y = 2 \times 10^{-7} \sin (0.5 \times 10^3 x + 1.5\ 10^{11}\ t)$T. The electromagnetic wave is
(a) a visible light (b) an infrared rays
(c) a microwave (d) a radio wave

4. The dielectric constant of air is 1.006. The speed of electromagnetic wave travelling in air is $a \times 10^8$ m s^{-1}, where a is about
(a) 3 (b) 3.88
(c) 2.5 (d) 3.2

5. What is the name given to that part of the electromagnetic spectrum which is used for taking photographs of earth under foggy conditions from great heights?
(a) Ultraviolet rays (b) Visible rays
(c) Infrared rays (d) Microwaves

6. The electromagnetic wave having the shortest wavelength is
(a) X-rays (b) γ-rays
(c) infrared rays (d) microwaves

7. The electric field (in N C^{-1}) in an electromagnetic wave is given by $E = 50 \sin \omega\left(t - \frac{x}{c}\right)$. The energy stored in a cylinder of cross-section 10 cm^2 and length 100 cm along the x-axis will be
(a) 5.5×60^{-12} J (b) 1.1×10^{-11} J
(c) 2.2×10^{-11} J (d) 1.65×10^{-11} J

8. A parallel plate capacitor with plate area A and separation between the plates d is charged by a constant current I. Consider a plane surface of area $\frac{A}{3}$ parallel to the plates and drawn symmetrically between the plates. The displacement current through this area is
(a) I (b) $\frac{I}{3}$
(c) $\frac{2I}{3}$ (d) $\frac{I}{6}$

9. Which of the following types of electromagnetic radiation travels at the greatest speed in vacuum?
(a) Radio waves
(b) Visible light
(c) X-rays
(d) All of these travel at the same speed

10. An electromagnetic wave is transposing energy in the negative y-direction. At one point and one instant the magnetic field is in the positive x-direction. The electric field at that point and instant in
(a) positive y-direction
(b) negative y-direction
(c) positive z-direction
(d) negative z-direction

11. A plane electromagnetic wave travelling along the x-direction has a wavelength of 3 mm. The variation in the electric field occurs in the y-direction with an amplitude 66 V m^{-1}. The equations for the electric and magnetic fields as a function of x and t are respectively
(a) $E_y = 33\cos\pi \times 10^{11}(t - \frac{x}{c})$
$B_z = 1.1 \times 10^{-7}\cos\pi \times 10^{11}(t - \frac{x}{c})$
(b) $E_y = 11\cos 2\pi \times 10^{11}(t - \frac{x}{c})$
$B_y = 11 \times 10^{-7}\cos 2\pi \times 10^{11}(t - \frac{x}{c})$
(c) $E_x = 33\cos\pi \times 10^{11}(t - \frac{x}{c})$
$B_x = 11 \times 10^{-7}\cos\pi \times 10^{11}(t - \frac{x}{c})$
(d) $E_y = 66\cos 2\pi \times 10^{11}(t - \frac{x}{c})$
$B_z = 2.2 \times 10^{-7}\cos 2\pi \times 10^{11}(t - \frac{x}{c})$

12. An electromagnetic wave going through vacuum is described by
$E = E_0 \sin(kx - \omega t)$; $B = B_0 \sin(kx - \omega t)$. Then,
(a) $E_0 k = B_0 \omega$
(b) $E_0 B_0 = \omega k$
(c) $E_0 \omega = B_0 k$
(d) none of these

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13. The average magnetic energy density of an electromagnetic wave of wavelength λ travelling in free space is given by

(a) $\frac{B^2}{2\lambda}$ (b) $\frac{B^2}{2\mu_0}$

(c) $\frac{B^2}{\mu_0\lambda}$ (d) $\frac{B}{\mu_0\lambda}$

14. A plane electromagnetic wave, $E_z = 100\cos(6 \times 10^8 t + 4x)$ V m^{-1}, propagating in a medium of dielectric constant is

(a) 1.5 (b) 2.0

(c) 2.4 (d) 4.0

15. Assume that a lamp radiates power P uniformly in all directions. What is the magnitude of electric field strength at a distance r from the lamp?

(a) $\frac{P}{\pi c\varepsilon_0 r^2}$ (b) $\frac{P}{2\pi c\varepsilon_0 r^2}$

(c) $\sqrt{\frac{P}{2\pi\varepsilon_0 r^2 c}}$ (d) $\sqrt{\frac{P}{\pi\varepsilon_0 c r^2}}$

16. Instantaneous displacement current of 1.0 A in the space between the parallel plates of 1 μF capacitor can be established , by rate of change of potential difference

(a) 10^5 V s^{-1} (b) 10^6 V s^{-1}

(c) 10^{-6} V s^{-1} (d) 10^7 V s^{-1}

17. A parallel plate capacitor with plate area A and separation between the plates d, is charged by a constant current I. Consider a plane surface of area $A/2$ parallel to the plates and drawn between the plates. The displacement current through this area is

(a) I (b) $\frac{I}{2}$

(c) $\frac{I}{4}$ (d) $\frac{I}{8}$

18. Maxwell in his famous equations of electromagnetism introduced the concept of

(a) alternating current
(b) displacement current
(c) impedance
(d) reactance

19. A plane electromagnetic wave travels in free space along X-direction. If the value of $\vec{B}$ (in tesla) at a particular point in space and time is $1.2 \times 10^{-8}\hat{k}$, the value of $\vec{E}$ (in V m^{-1}) at that point is

(a) $1.2\hat{j}$ (b) $3.6\hat{k}$

(c) $1.2\hat{k}$ (d) $3.6\hat{j}$

20. If a variable frequency ac source is connected to a capacitor then with decrease in frequency the displacement current will

(a) increase
(b) decrease
(c) remain constant
(d) first decrease then increase

21. The charge on a parallel plate capacitor varies as $q = q_0 \cos 2\pi\upsilon t$. The plates are very large and close together (area = A, separation = d). The displacement current through the capacitor is

(a) $q_0 2\pi\upsilon \sin\pi\upsilon t$ (b) $-q_0 2\pi\upsilon \sin 2\pi\upsilon t$

(c) $q_0 2\pi \sin\pi\upsilon t$ (d) $q_0 \pi\upsilon \sin 2\pi\upsilon t$

22. Displacement current goes through the gap between the plates of a capacitor when the charge on the capacitor

(a) is changing with time (b) decreases
(c) does not change (d) decreases to zero

23. In order to establish an instantaneous displacement current of 1 mA in the space between the plates of 2 μF parallel plate capacitor, the potential difference need to apply is

(a) 100 V s^{-1} (b) 200 V s^{-1}

(c) 300 V s^{-1} (d) 500 V s^{-1}

24. The conduction current is same as displacement current when source is

(a) ac only (b) dc only
(c) either ac or dc (d) neither dc nor ac

25. If μ_0 be the permeability and ε_0 be the permittivity of a medium, then its refractive index is given by

(a) $\frac{1}{\sqrt{\mu_0\varepsilon_0}}$ (b) $\frac{1}{\mu_0\varepsilon_0}$

(c) $\sqrt{\mu_0\varepsilon_0}$ (d) $\mu_0\varepsilon_0$

26. Electromagnetic wave consists of periodically oscillating electric and magnetic vectors

(a) in mutually perpendicular planes but vibrating with a phase difference of π
(b) in mutually perpendicular planes but vibrating with a phase difference of $\frac{\pi}{2}$
(c) in randomly oriented planes but vibrating in phase
(d) in mutually perpendicular planes but vibrating in phase.

27. About 6% of the power of a 100 W light bulb is converted to visible radiation. The average intensity of visible radiation at a distance of 8 m is (Assume that the radiation is emitted isotropically and neglect reflection.

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(a) 3.5×10^{-3} W m^{-2}
(b) 5.1×10^{-3} W m^{-2}
(c) 7.2×10^{-3} W m^{-2}
(d) 2.3×10^{-3} W m^{-2}

28. A plane electromagnetic wave travels in vacuum along z-direction. If the frequency of the wave is 40 MHz then its wavelength is
(a) 5 m (b) 7.5 m
(c) 8.5 m (d) 10 m

29. The source of electromagnetic waves can be charge, when
(a) moving with a constant velocity
(b) moving in a circular orbit
(c) falling in an electric field
(d) both (b) and (c)

30. The electric field associated with an electromagnetic wave in vacuum is given by $\vec{E} = 40 \cos(kz - 6 \times 10^8 t)\,\hat{i}$, where E, z and t are in volt per meter, meter and second respectively. The value of wave vector k is
(a) 2 m^{-1} (b) 0.5 m^{-1}
(c) 6 m^{-1} (d) 3 m^{-1}

31. A radio can tune to any station in 7.5 MHz to 12 MHz band. The corresponding wavelength band is
(a) 40 m to 25 m (b) 30 m to 25 m
(c) 25 m to 10 m (d) 10 m to 5 m

32. An electromagnetic wave of intensity I falls on a surface kept in vacuum and exerts radiation pressure P on it. Which of the following statement is not true?
(a) Radiation pressure is I/c if the wave is totally absorbed.
(b) Radiation pressure is I/c if the wave is totally reflected.
(c) Radiation pressure is 2 I/c if the wave is totally reflected.
(d) Radiation pressure is in the range $I/c < p > 2\ I/c$ for real surfaces.

33. A plane electromagnetic wave of frequency 25 MHz travels in free space along x-direction. At a particular point in space and time, electric field $E = 6.3$ V m^{-1}. The magnitude of magnetic field B at this point is
(a) 1.2×10^{-6} T (b) 1.2×10^{-8} T
(c) 2.1×10^{-6} T (d) 2.1×10^{-8} T

34. A plane electromagnetic wave is incident on a material surface. The wave delivers momentum p and energy E. Then
(a) $p \neq 0, E \neq 0$ (b) $p = 0, E = 0$
(c) $p = 0, E \neq 0$ (d) $p \neq 0, E = 0$

35. Which of the following has/have zero average value in a plane electromagnetic wave?
(a) Both magnetic and electric fields
(b) Electric field only
(c) Magnetic field only
(d) None of these

36. The electric field of an electromagnetic wave travelling through vacuum is given by the equation $E = E_0 \sin(kx - \omega t)$. The quantity that is independent of wavelength is
(a) $k\omega$ (b) $\frac{k}{\omega}$
(c) $k^2\omega$ (d) ω

37. The amplitude of the magnetic field of a harmonic electromagnetic wave in vacuum is $B_0 = 510$ nT. The amplitude of the electric field part of the wave is
(a) 120 N C^{-1} (b) 134 N C^{-1}
(c) 510 N C^{-1} (d) 153 N C^{-1}

38. Radiations of intensity 0.5 W m^{-2} are striking a metal plate. The pressure on the plate is
(a) 0.166×10^{-8} N m^{-2} (b) 0.332×10^{-8} N m^{-2}
(c) 0.111×10^{-8} N m^{-2} (d) 0.083×10^{-8} N m^{-2}

39. The dimensions of $(\mu_0\ \varepsilon_0)^{-1/2}$ are
(a) $[L^{1/2}\ T^{-1/2}]$ (b) $[L^{-1}\ T]$
(c) $[LT^{-1}]$ (d) $[L^{-1/2}\ T^{1/2}]$

40. Molybdenum is used as a target element for the production of X-rays because it is
(a) light and can easily deflect electrons
(b) light and can absorb electrons
(c) a heavy element with a high melting point
(d) an element having high thermal conductivity.

41. The electric field part of an electromagnetic wave in a medium is represented by $E_x = 0$;
$E_y = 2.5$ N C^{-1} $\times$
$\cos[(2\pi \times 10^6$ rad s$^{-1})t - (\pi \times 10^{-2}$ rad m$^{-1})x]$;
$E_z = 0$. The wave is
(a) moving along the x-direction with frequency 10^6 Hz and wavelength 100 m
(b) moving along x-direction with frequency 10^6 Hz and wavelength 200 m
(c) moving along $-x$-direction with frequency 10^6 Hz and wavelength 200 m
(d) moving along y-direction with frequency $2\pi \times 10^6$ Hz and wavelength 200 m.

42. The amplitude of magnetic field in a parallel beam of light of intensity 2.0 W m^{-2} is
(a) 1.3×10^{-7} T (b) 1.3×10^{-6} T
(c) 1.3×10^{-5} T (d) 1.3×10^{-8} T

43. Light with an energy flux of 18 W cm^{-2} falls on a non-reflecting surface at normal incidence. If the surface has an area of 20 cm^2, the total momentum delivered to the surface during a span of 30 minutes is

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(a) 2.16×10^{-3} kg m s^{-1} (b) 2.16×10^{-4} kg m s^{-1}
(c) 4.32×10^{-3} kg m s^{-1} (d) 4.32×10^{-4} kg m s^{-1}

44. If λ_v, λ_x and λ_m represent the wavelengths of visible light, X-rays and microwaves respectively, then
(a) $\lambda_m > \lambda_x > \lambda_v$ (b) $\lambda_v > \lambda_m > \lambda_x$
(c) $\lambda_v > \lambda_x > \lambda_m$ (d) $\lambda_m > \lambda_v > \lambda_x$

45. An earth orbiting satellite has solar energy collecting panel with total area 5 m^2. If solar radiations are perpendicular and completely absorbed, the average force associated with the radiation pressure is (solar constant = 1.4 kW m^{-2}).
(a) 2.33×10^{-3} N (b) 2.33×10^{-4} N
(c) 2.33×10^{-5} N (d) 2.33×10^{-6} N

DAY 22 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____
(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (c) : The time varying electric and magnetic fields are mutually perpendicular to each other and also perpendicular to the direction of propagation of the wave.

2. (b) : Total average energy density of electromagnetic wave is

$$< u > = \frac{1}{2}\varepsilon_0 E_{rms}^2 + \frac{1}{2\mu_0} B_{rms}^2$$

$$= \frac{1}{2}\varepsilon_0 E_{rms}^2 + \frac{1}{2\mu_0}\left(\frac{E_{rms}^2}{c^2}\right) \left(\because B_{rms} = \frac{E_{rms}}{c}\right)$$

$$= \frac{1}{2}\varepsilon_0 E_{rms}^2 + \frac{1}{2\mu_0} E_{rms}^2 \varepsilon_0 \mu_0$$

$$= \frac{1}{2}\varepsilon_0 E_{rms}^2 + \frac{1}{2}\varepsilon_0 E_{rms}^2 = \varepsilon_0 E_{rms}^2$$

$$= (8.85 \times 10^{-12}) \times (720)^2 = 4.58 \times 10^{-6} \text{ J m}^{-3}$$

3. (c) : $B_y = 2 \times 10^{-7} \sin(0.5 \times 10^3 x + 1.5 \times 10^{11} t)$ T

Comparing with the standard equation, we get

$B_y = B_0 \sin(kx + \omega t)$

$k = 0.5 \times 10^3$

$$\Rightarrow \quad \lambda = \frac{2\pi}{0.5 \times 10^3} = 0.01256 \text{ m}$$

The wavelength range of microwaves is 10^{-3} m to 0.3 m. The wavelength of this wave lies between 10^{-3} m to 0.3 m, so the equation represents a microwaves.

4. (a) : The speed of the electromagnetic wave in vacuum is

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3 \times 10^8 \text{ m s}^{-1}$$

Air acts almost as vacuum, therefore

$3 \times 10^8 = a \times 10^8$ or $a = 3$ (approximately)

5. (c) : Infra-red rays are used for taking photographs in foggy conditions.

6. (b) : The increasing order of given electromagnetic wave is as follows :

$\lambda_{\gamma\text{-rays}} < \lambda_{X\text{-rays}} < \lambda_{\text{infrared}} < \lambda_{\text{microwave}}$

7. (b) : Energy contained in a cylinder

U = average energy density × volume

$$= \frac{1}{2}\varepsilon_0 E_0^2 \times Al$$

$$= \frac{1}{2} \times (8.85 \times 10^{-12}) \times (50)^2 \times (10 \times 10^{-4}) \times 1$$

$$= 1.1 \times 10^{-11} \text{ J}$$

8. (b) : The displacement current = conduction current = I corresponding to area A. Therefore displacement current for area $\frac{A}{3}$ is $\frac{I}{3}$.

9. (d) : All electromagnetic waves travel with the same speed c ($= 3 \times 10^8$ m s^{-1}) in vacuum.

10. (d) : In an electromagnetic wave, the direction of energy flow is along the direction of the wave propagation. Therefore, the wave propagates along negative y-direction. Magnetic field ($\vec{B}$) is along the positive x-direction and the wave propagates along negative y-direction. Therefore, electric field (E) should be in a direction perpendicular to both x and y-axes. Using vector algebra $\vec{E} \times \vec{B}$ should be along negative y-direction.

Since $(-\hat{j}) = (-\hat{k}) \times (\hat{i})$, $\vec{E}$ is along negative z-direction.

11. (d) : Here, $E_0 = 66$ V m^{-1}, $\lambda = 3$ mm $= 3 \times 10^{-3}$ m

$$\therefore \quad B_0 = \frac{E_0}{c} = \frac{66}{3 \times 10^8} = 2.2 \times 10^{-7} \text{ T}$$

$$\omega = 2\pi\upsilon = \frac{2\pi c}{\lambda} = \frac{2\pi \times 3 \times 10^8}{3 \times 10^{-3}} = 2\pi \times 10^{11}$$

$\vec{E}$ is along y-direction and the wave propagates along x-direction. Therefore, $\vec{B}$ should be in a direction perpendicular to both x and y-axes. Using vector algebra $\vec{E} \times \vec{B}$ should be along x-direction.

Since $(\hat{i}) = (+\hat{j}) \times (+\hat{k})$, $\vec{B}$ is along the z-direction.

$\therefore$ The equation for the electric field along y-direction in the electromagnetic wave is given by

$$E_y = E_0 \cos\omega(t - \frac{x}{c}) = 66 \cos 2\pi \times 10^{11}(t - \frac{x}{c})$$

and the equation for the magnetic field along z-direction in the electromagnetic wave is given by

$$B_z = B_0 \cos\omega(t - \frac{x}{c}) = 2.2 \times 10^{-7} \cos 2\pi \times 10^{11}(t - \frac{x}{c})$$

12. (a) : $\frac{E_0}{B_0} = \frac{\omega}{k}$ or $E_0 k = B_0 \omega$

13. (b) : The average magnetic energy density of an electromagnetic wave travelling in free space is

$$u_B = \frac{B^2}{2\mu_0}$$

14. (d) : $E_z = 100\cos(6 \times 10^8 t + 4x)$ V m^{-1}

Comparing the given equation with

$E_z = E_0 \cos(\omega t + kx)$,

We get

$\omega = 6 \times 10^8$ rad s^{-1}, $k = 4$ rad m^{-1}

Speed of electromagnetic wave in a medium is

$$v = \frac{\omega}{k} = \frac{6 \times 10^8 \text{ rad s}^{-1}}{4 \text{ rad m}^{-1}} = \frac{3 \times 10^8}{2} \text{ m s}^{-1}$$

Dielectric constant,

$$K = \left(\frac{c}{v}\right)^2 = \left(\frac{3 \times 10^8 \text{ m s}^{-1}}{\frac{3 \times 10^8}{2} \text{ m s}^{-1}}\right)^2 = 4$$

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15. (c) : A lamp radiates light uniformly in all directions. Therefore, intensity I at a distance r from the lamp is

$$I = \frac{\text{Power}}{\text{Area}} = \frac{P}{4\pi r^2} \quad ...(i)$$

Intensity of the electromagnetic wave is

$$I = < u > c = \frac{1}{2}\varepsilon_0 E_0^2 c \quad ...(ii)$$

Equating (i) and (ii), we get

$$\frac{1}{2}\varepsilon_0 E_0^2 c = \frac{P}{4\pi r^2}$$

$$E_0 = \sqrt{\frac{2P}{4\pi\varepsilon_0 r^2 c}} = \sqrt{\frac{P}{2\pi\varepsilon_0 r^2 c}}$$

16. (b) : $I_d = \varepsilon_0 \frac{d\phi_E}{dt} = \varepsilon_0 A \frac{d}{dt}\left(\frac{V}{d}\right)$

or $I_d = \frac{\varepsilon_0 A}{d} \times \frac{dV}{dt} = C\frac{dV}{dt}$ or $\frac{dV}{dt} = \frac{I_d}{C} = \frac{1.0}{10^{-6}} = 10^6 \text{ V s}^{-1}$

17. (b) : Charge on capacitor plates at time t is, $q = It$. Electric field between the plates at this instant is

$$E = \frac{q}{A\varepsilon_0} = \frac{It}{A\varepsilon_0} \quad ...(i)$$

Electric flux through the given area $A/2$ is

$$\phi_E = \left(\frac{A}{2}\right)E = \frac{It}{2\varepsilon_0} \quad \text{(Using (i))} \quad ...(ii)$$

Therefore, displacement current

$$I_d = \varepsilon_0 \frac{d\phi_E}{dt} = \varepsilon_0 \frac{d}{dt}\left(\frac{It}{2\varepsilon_0}\right) = \frac{I}{2} \quad \text{(Using (ii))}$$

18. (b)

19. (d) : Here, $\vec{B} = 1.2 \times 10^{-8}\,\hat{k}$ T

The magnitude of $\vec{E}$ is

$$E = Bc = (1.2 \times 10^{-8} \text{ T})(3 \times 10^8 \text{ m s}^{-1})$$
$$= 3.6 \text{ V m}^{-1}$$

$\vec{B}$ is along Z-direction and the wave propagates along X-direction. Therefore $\vec{E}$ should be in a direction perpendicular to both X and Z axes. Using vector algebra $\vec{E} \times \vec{B}$ should be along X-direction.

Since $(+\hat{j}) \times (+\hat{k}) = \hat{i}$, $\vec{E}$ is along the Y-direction.

Thus, $\vec{E} = 3.6\,\hat{j}$ Vm^{-1}

20. (b) : Current through capacitor,

$$I = \frac{E}{X_C} = \frac{E}{\frac{1}{\omega C}} = \omega CE = 2\pi\upsilon CE \quad \text{or} \quad I \propto \upsilon$$

$\therefore$ decrease in frequency υ of ac source decreases the conduction current. As displacement current is equal to conduction current, decrease in υ decreases displacement current in circuit.

21. (b) : Displacement current, I_D = conduction current, I_C

$$\therefore \quad \frac{dq}{dt} = \frac{d}{dt}\left[q_0 \cos 2\pi\upsilon t\right] = -\,q_0\, 2\pi\upsilon \sin 2\pi\upsilon t$$

22. (a) : Displacement current arises when electric field in a region is changing with time. It will be so if the charge on a capacitor is changing with time.

23. (d) : $I_D = 1 \text{ mA} = 10^{-3} \text{ A}$

$C = 2\ \mu\text{F} = 2 \times 10^{-6}$ F

$$I_D = I_C = \frac{d}{dt}(CV) = C\frac{dV}{dt}$$

Therefore, $\frac{dV}{dt} = \frac{I_D}{C} = \frac{10^{-3}}{2 \times 10^{-6}} = 500 \text{ V s}^{-1}$

Therefore, applying a varying potential difference of 500 V s^{-1} would produce a displacement current of desired value.

24. (c)

25. (c) : Refractive index of medium is $= \frac{c}{v}$

where $c = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$

and $v = \frac{1}{\sqrt{\mu_0\varepsilon_0\mu_r\varepsilon_r}}$

$$\therefore \quad \mu = \frac{1/\sqrt{\mu_0\varepsilon_0}}{1/\sqrt{\mu_0\varepsilon_0\mu_r\varepsilon_r}} = \sqrt{\mu_r\varepsilon_r}$$

Given $\mu_r = \mu_0$ and $\varepsilon_r = \varepsilon_0$ then $\mu = \sqrt{\mu_0\varepsilon_0}$

26. (d) : Electromagnetic wave consists of periodically oscillating electric and magnetic vectors in mutually perpendicular planes but vibrating in phase.

27. (c) : Here, power of bulb = 100 W

$$\text{As intensity, } I = \frac{\text{Power of visible light}}{\text{area}}$$
$$= \frac{100 \times 6/100}{4\pi(8)^2} = 7.2 \times 10^{-3} \text{ W m}^{-2}$$

28. (b) : Wavelength, $\lambda = \frac{c}{\upsilon} = \frac{3 \times 10^8 \text{ m s}^{-1}}{40 \times 10^6 \text{ s}^{-1}} = 7.5 \text{ m}$

29. (d) : An electromagnetic wave can be produced by accelerated or oscillating charge. In options (b) and (c), the charge is in accelerated state, hence will be a source of electromagnetic waves.

30. (a) : Compare the given equation with $E = E_0\cos(kz - \omega t)$

We get, $\omega = 6 \times 10^8 \text{ s}^{-1}$

Wave vector, $k = \frac{\omega}{c} = \frac{6 \times 10^8 \text{ s}^{-1}}{3 \times 10^8 \text{ m s}^{-1}} = 2 \text{ m}^{-1}$

31. (a) : Here, $\upsilon_1 = 7.5$ MHz, $\upsilon_2 = 12$ MHz

$$\therefore \quad \lambda_1 = \frac{c}{\upsilon_1} = \frac{3 \times 10^8}{7.5 \times 10^6} = 40 \text{ m}$$

$$\text{and} \quad \lambda_2 = \frac{c}{\upsilon_2} = \frac{3 \times 10^8}{12 \times 10^6} = 25 \text{ m}$$

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32. (b) : Momentum per unit time per unit area

$$= \frac{\text{intensity}}{\text{speed of wave}} = \frac{I}{c}$$

Change in momentum per unit time per unit area = $\Delta I/c$ = radiation pressure (P), *i.e.* $P = \Delta I/c$.

Momentum of incident wave per unit time per unit area = I/c

When wave is fully absorbed by the surface, the momentum of the reflected wave per unit time per unit area = 0

Radiation pressure (P) = change in momentum per unit time

per unit area $= \frac{\Delta I}{c} = \frac{I}{c} - 0 = \frac{I}{c}$

When wave is totally reflected, then momentum of the reflected wave per unit time per unit area = $-I/c$.

Radiation pressure $(P) = \frac{I}{c} - \left(-\frac{I}{c}\right) = \frac{2I}{c}$

Here, P lies between $\frac{I}{c}$ and $\frac{2I}{c}$

33. (d) : As, $B = \frac{E}{c} = \frac{6.3}{3\times10^8} = 2.1\times10^{-8}$ T

34. (a) : When plane electromagnetic wave is incident on a material surface, the wave delivers some momentum and energy to the surface and hence $p \neq 0$ and $E \neq 0$.

35. (a) : Both magnetic and electric fields have zero average value in a plane electromagnetic wave.

36. (b) : Here, $k = \frac{2\pi}{\lambda}, \omega = 2\pi\upsilon$

$\therefore \quad \frac{k}{\omega} = \frac{2\pi/\lambda}{2\pi\upsilon} = \frac{1}{\upsilon\lambda} = \frac{1}{c} \qquad (\because c = \upsilon\lambda)$

where c is the speed of electromagnetic wave in vacuum. It is a constant whose value is 3×10^8 m s^{-1}.

37. (d) : Here, $B_0 = 510\ n\text{T} = 510 \times 10^{-9}$ T

$E_0 = cB_0 = 3 \times 10^8 \times 510 \times 10^{-9} = 153$ N C^{-1}

38. (a) : $P = \frac{I}{c} = \frac{0.5}{3 \times 10^8} = 0.166 \times 10^{-8}$ N m^{-2}

39. (c) : $\frac{1}{\sqrt{\mu_0 \in_0}} = c$ (speed of light) and dimensions of c are [LT^{-1}].

40. (c)

41. (b) : Given, $E_x = 0$,

$E_y = 2.5$ N C$^{-1} \times \cos[(2\pi \times 10^6$ rad s$^{-1})t - (\pi \times 10^{-2}$ rad m$^{-1})x]$,

$E_z = 0$. This shows that the wave is propagating along x-axis. Comparing the given equation with $E = E_0 \cos(\omega t - kx)$, we have

$\omega = 2\pi \times 10^6$

or $2\pi\upsilon = 2\pi \times 10^6 \Rightarrow \upsilon = 10^6$ Hz

and $\frac{2\pi}{\lambda} = k = \pi \times 10^{-2} \Rightarrow \lambda = \frac{2\pi}{\pi \times 10^{-2}} = 200$ m

42. (a) : Intensity of a wave $= \frac{\text{energy/time}}{\text{area}} = \frac{\text{power}}{\text{area}}$

or $I = u_{av}\, c = \frac{1}{2\mu_0} B_0^2 c \Rightarrow B_0 = \sqrt{\frac{2\mu_0 I}{c}}$

$B_0 = \sqrt{\frac{2\times(4\pi\times10^{-7})\times2}{3\times10^8}} = 1.3 \times 10^{-7}$ T

43. (a) : Total energy falling on the surface = Energy flux × time × area

$\Rightarrow U = (18$ W cm$^{-2}) \times (30 \times 60$ s$) \times (20$ cm$^2)$

$= 6.48 \times 10^5$ J

Total momentum delivered to the surface

$$p = \frac{U}{c} = \frac{6.48\times10^5}{3\times10^8} = 2.16 \times 10^{-3} \text{ kg m s}^{-1}$$

44. (d) : As wavelength range of microwaves is from 0.1 m to 1mm, visible light is from 700 nm to 400 nm and X-rays is from 1 nm to 10^{-3} nm

$\therefore \quad \lambda_m > \lambda_v > \lambda_x$

45. (c) : As, power = solar constant × area

$= (1.4 \times 10^3) \times 5$

$\therefore$ Force $= \frac{\text{solar constant} \times \text{area}}{\text{speed of light}}$

$= \frac{1.4\times10^3\times5}{3\times10^8} = 2.33 \times 10^{-5}$ N

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Ray Optics and Optical Instruments

Reflection of Light

Reflection is the phenomenon by virtue of which the light beam interacting with a surface separating the two media bounces back into the same media.

Laws of reflection

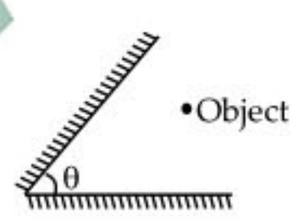
- The angle of incidence equals to the angle of reflection.
- Incident ray, the normal ray, and the reflected ray lie in the same plane.

Properties of images formed by plane mirror

- The image is virtual, erect and laterally reversed.
- Image size = object size.
- Object distance is equal to image distance.
- If the plane mirror is rotated through an angle θ, the reflected ray is rotated through an angle 2θ.

When two plane mirrors are kept facing each other at an angle θ and an object is placed between them, then multiple images of the object are formed as a result of successive reflection.

The number of images, n is given by



Case 1 : If $m = \frac{360^\circ}{\theta}$ is even integer, number of images formed $n = (m - 1)$ for all positions of object.

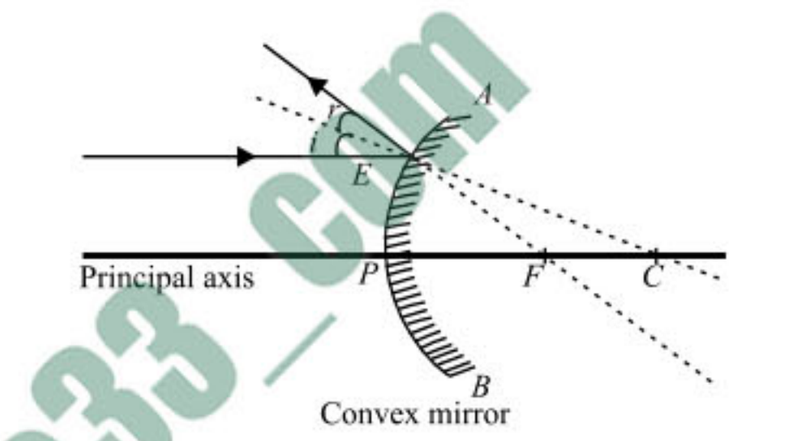
Case 2 : If $m = \frac{360^\circ}{\theta}$ is odd integer, number of images formed $n = m$

Case 3 : If $m = \frac{360^\circ}{\theta}$ is a fraction, number of images formed will equal to its integral part.

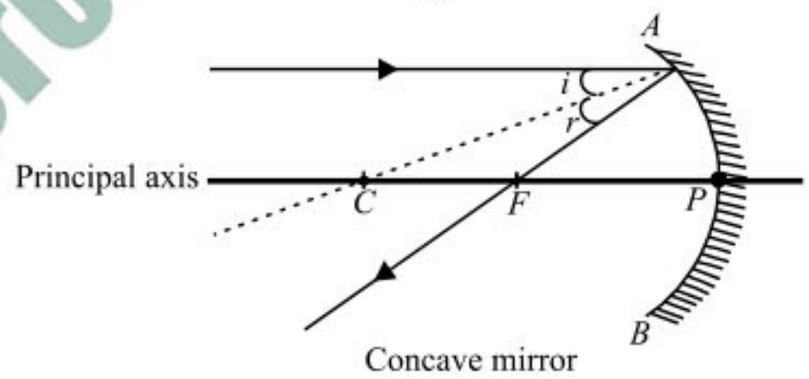
When two plane mirrors are placed parallel to each other then $\theta = 0^\circ \Rightarrow n = \infty$. Therefore, infinite number of images are formed.

Spherical Mirrors

Spherical mirror is a mirror whose reflecting surface is the part of a sphere. If the reflection occurs from the outer surface of the sphere, the mirror is called a convex mirror as shown in figure (a). If the reflection occurs from the inner surface of the sphere, then mirror is called a concave mirror as shown in figure (b).



(a)



(b)

Some terms related to spherical surfaces

- ***Pole:*** It is the midpoint of the mirror.
- **Centre of curvature :** It is the midpoint of spherical surface of which the mirror is a part (point *C* in figure).
- **Radius of curvature :** It is the radius of spherical surface of which the mirror is a part (distance *CP* in figure).
- **Principal axis :** It is the straight line joining the pole of the mirror and its centre of curvature (*C*).
- **Principal focus :** It is a point on the principal axis of the mirror at which the light rays coming parallel to the axis actually meet after reflection or appear to meet. (Point *F* in figure).
- **Focal length(*f*) :** It is the distance between the pole (*P*) and principal focus (*F*).

Sign conventions

- Heights measured upwards and normal to the principal axis of the mirror are taken as positive, while those measured downwards are taken as negative.
- Distances measured in the direction of incident light are positive, and those measured in opposite direction are taken as negative.
- All distance have to be measured from the pole of the mirror

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Location, size of image and nature of image formed by spherical mirrors

	Position of object	Position of image	Nature of image
(a) For concave mirror			
(i)	At infinity	At focus F	Real, inverted, diminished
(ii)	Beyond C	Between F and C	Real, inverted, diminished
(iii)	At C	At C	Real, inverted, same size
(iv)	Between F and C	Beyond C	Real, inverted, magnified
(v)	At F	At infinity	Real, inverted, magnified
(vi)	Between F and P	Behind the mirror	Virtual, erect, magnified
(b) For convex mirror			
(i)	*At infinity*	At F	Virtual, erect, diminished
(ii)	*In front of mirror*	Between P and F	Virtual, erect, diminished

Spherical Mirror Formula

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

Here, u is distance between object and pole of the mirror, v is the distance between image and pole of the mirror and f is the focal length of the mirror.

The focal length of a spherical mirror of radius R is given by

$$f=\frac{R}{2}$$

f (or R) is negative for concave or converging mirror and positive for convex or diverging mirror.

Transverse or linear magnification

$$m=\frac{\text{size of image}}{\text{size of object}}=-\frac{v}{u}$$

Here –ve magnification implies that image is inverted with respect to object while +ve magnification means that image is erect with respect to object.

Power of Mirror

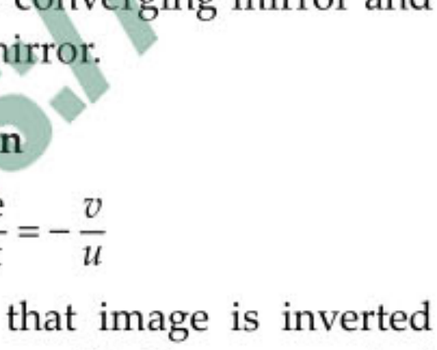
Power of mirror, $P=\frac{1}{f}$

where, f is taken in meter with proper sign *i.e.*, –ve for concave and +ve for convex.

Refraction of Light

The phenomenon of change in path of light as it goes from one medium to another is called refraction of light.

When a ray of light passes from optically rarer to denser medium it bends towards normal.



Whereas when a ray of light passes from optically denser to rarer medium it bends away from the mirror.

Laws of refraction

- The incident ray, refracted ray and normal to the rays, all lie in a same plane.
- The ratio of sine of angle of incidence to sine of angle of refraction is constant for a given pair of media known as refractive index of that pair of media, denoted by μ. This is also called Snell's law of refraction

Absolute refractive index

Refractive index of a medium with respect to vacuum (or in practice air) is known as absolute refractive index of the medium

$$\mu=\frac{c}{v}=\frac{\text{speed of light in vacuum}}{\text{speed of light in medium}}$$

General expression for Snell's law

$${}^{1}\mu_{2}=\frac{\mu_2}{\mu_1}=\frac{\left(\frac{c}{v_2}\right)}{\left(\frac{c}{v_1}\right)}=\frac{v_1}{v_2}$$

where c is the speed of light in air, v_1 and v_2 be the speeds of light in medium 1 and medium 2 respectively.

According to Snell's law,

$${}^{1}\mu_{2}=\frac{\sin i}{\sin r};\quad \frac{\mu_2}{\mu_1}=\frac{\sin i}{\sin r}$$

or $\mu_1 \sin i=\mu_2 \sin r$

Surrounding media

R.I. of medium 2 with respect to medium 1 is represented as ${}^{1}\mu_{2}$ or μ_{12} and here the ray of light travels from 1 to 2.

R.I. of medium 1 w.r.t. medium 2 is denoted by ${}^{2}\mu_{1}$.

$$\frac{1}{{}^{2}\mu_{1}}={}^{1}\mu_{2}\quad\text{or}\quad {}^{1}\mu_{2}\times{}^{2}\mu_{1}=1$$

If glass is surrounded by water, R.I. $={}^{w}\mu_{g}$

$$=\frac{\text{Velocity of light in water}}{\text{Velocity of light in glass}}$$

$${}^{w}\mu_{g}=\frac{{}^{a}\mu_{g}}{{}^{a}\mu_{w}}=\frac{3/2}{4/3}=\frac{9}{8}$$

Quantities which remain constant during refraction are

- Frequency of light
- Phase angle.

Quantities which change during refraction are

- Speed of light : Denser the medium, less the velocity.
- Wavelength of light : Denser the medium, less the wavelength.
- Amplitude of light.
- Intensity of light : This is due to the partial reflection and partial absorption of light.

Apparent depth

If an object is placed below the surface of water or under a glass slab, it appears to be raised. *i.e.* the apparent depth is

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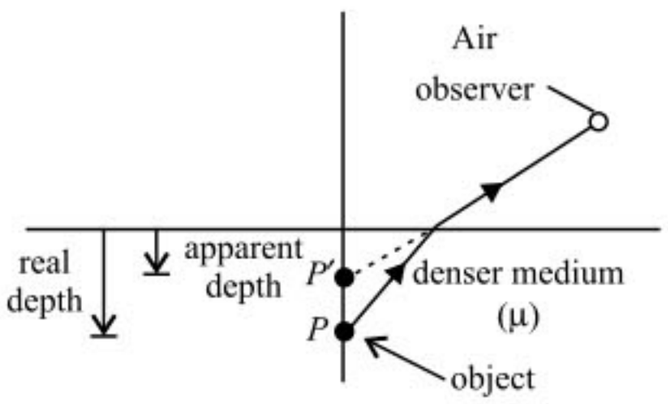
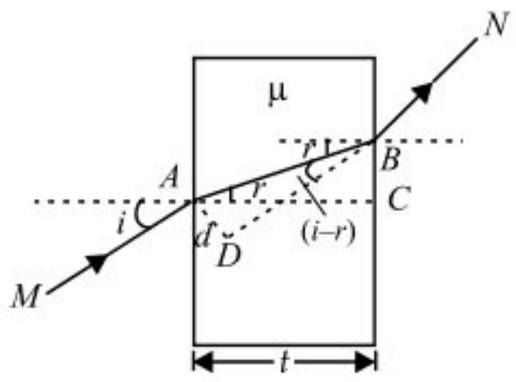
less than the real depth. This is due to refraction. Refractive index (μ) can also be given as

$$\mu = \frac{\text{Real depth}}{\text{Apparent depth}}$$



Lateral shifting due to slab

The perpendicular distance between the incident ray and the emergent ray, when the light is incident obliquely on a parallel sided refracting slab, is called lateral shift.

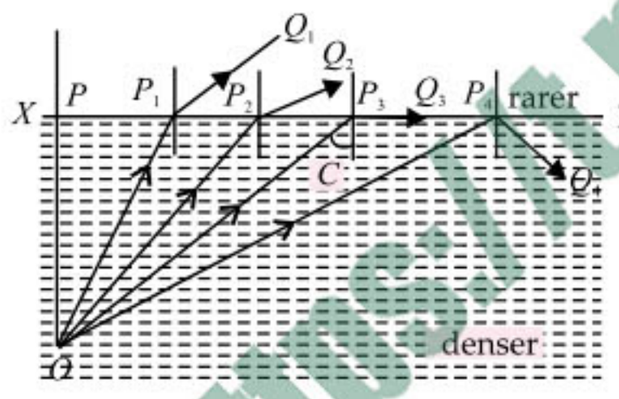


In figure, distance d is lateral shift and is given as

$$d = \frac{t}{\cos r}\sin(i-r), \quad t = \text{thickness of slab}$$

Total Internal Reflection

Total internal reflection is the phenomenon of reflection of light into the denser medium from the boundary of the denser medium and rarer medium.



The angle of incidence (i) in denser medium for which the angle of refraction in rarer medium is 90° is called the critical angle for the pair of media under consideration. It is normally denoted by C.

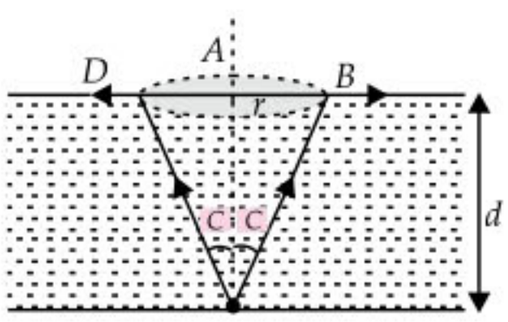
Critical angle depends on

- Nature of medium
- Wavelength of light

Critical angle for red light is more than that for blue light.

A diver in water at a depth d sees the world outside through a horizontal circle of radius

$$r = d\tan C = \frac{d}{\sqrt{\mu^2 - 1}}$$



Applications of total internal reflection

- The brilliance of diamond is due to the phenomenon of total internal reflection.
- Mirages in deserts are also due to total internal reflection.
- The working of optical fibre is based on the phenomenon of total internal reflection.

Refraction from a Spherical Surface

The portion of a refracting medium, whose curved surface forms the part of a sphere, is known as spherical refracting surface.

Spherical refracting surface of two types :

- Convex refracting spherical surface
- Concave refracting spherical surface

Sign conventions for spherical refracting surface are the same as those for spherical mirrors.

When the object is situated in rarer medium, the relation between μ_1 (refractive index of rarer medium) μ_2 (refractive index of the spherical refracting surface) and R (radius of curvature) with the object and image distances is given by

$$-\frac{\mu_1}{u} + \frac{\mu_2}{v} = \frac{\mu_2 - \mu_1}{R}$$

When the object is situated in denser medium, the relation between μ_1, μ_2, R, u and v can be obtained by interchanging μ_1 and μ_2. In that case, the relation becomes

$$-\frac{\mu_2}{u} + \frac{\mu_1}{v} = \frac{\mu_1 - \mu_2}{R} \quad \text{or} \quad -\frac{\mu_1}{v} + \frac{\mu_2}{u} = \frac{\mu_2 - \mu_1}{R}$$

These formulae are valid for both convex and concave spherical surfaces

Lens

Lens is a transparent medium bounded by two surfaces, at least one of them must be curved. A lens is said to be thin if the gap between two surfaces is very small.

Convex lens or converging lens

When a lens is thicker in the middle than at the edges it is known as convex lens or converging lens. These are of three types :

- Double convex lens or biconvex lens
- Plano convex lens
- Concavo convex lens

Concave lens or diverging lens

When the lens is thicker at the edges than in the middle it is known as concave lens or diverging lens. These are of three types :

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- Double convex lens or biconcave lens
- Plano concave lens
- Convexo concave lens

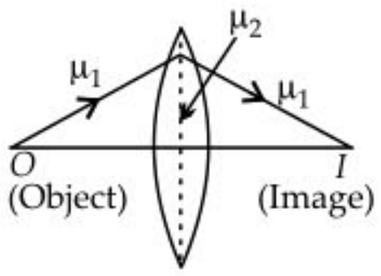
Biconcave lens | Plano concave lens | Convexo concave lens

Sign conventions

The sign conventions for thin lenses are the same as those of spherical mirrors except that instead of the pole of the mirror, we now use optical centre of a lens.

Lens Maker's Formula

Consider the thin lens with two refraction surfaces having radii of curvature equal to R_1 and R_2 respectively.



The refractive indices of this surrounding medium and of the material of the lens are μ_1 and μ_2 respectively.
Then, focal length is given by,

$$\frac{1}{f}=\left(\frac{\mu_2}{\mu_1}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

Limitations of the lens maker's formula

- The lens should be thin so that the separation between the two refracting surfaces is small.
- The medium on either side of the lens should be same if any of the limitation is violated then we have to use the refraction at the curved surface formula for both the surfaces.

Linear Magnification

$$m=\frac{v}{u}=\frac{I}{O}$$

- For a convex lens m is positive, when object lies between F and optical centre of lens, and image is virtual. m is negative when object lies beyond F and image is real.
- For a concave lens, m is positive as image is always erect and virtual.

Areal magnification,

$$m_A=\frac{\text{area of image}}{\text{area of object}}=\frac{v^2}{u^2}=m^2$$

Power of the Lens

Power of the lens; $P=\frac{1}{f}$.

where f is taken in meters with proper sign, positive for convex and negative for concave. It is in diopter (D).

Combinations of the Lenses

For a system of lenses, the net power of the system is

$P_{eq}=P_1+P_2+P_3+.....$

The thin lenses are in close contact. The focal length of the net system can be written as

$$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}+\frac{1}{f_3}.....$$

When a convex and concave lens of equal focal length are placed in contact the equivalent focal length is equal to infinite. Therefore, the power becomes zero.

If the lenses are kept at a separation d, then the effective focal length is given as

$$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}-\frac{d}{f_1f_2}$$

If the lens is converging put +ve for its focal length and –ve for diverging lens.

$$P=P_1+P_2-dP_1P_2$$

Silvering of lenses

If any surface of a lens is silvered, it will ultimately behave as a mirror and the power of mirror thus formed will be equal to the sum of powers of the optical lenses and the mirrors in between.

Chromatic aberration

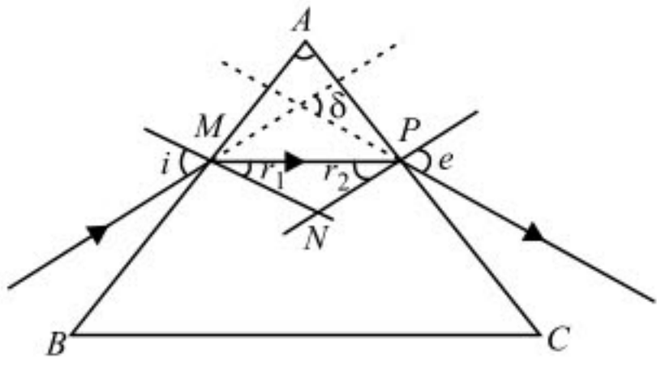
The refractive index is different for different colours, the image of an object illuminated by white light gets spread out. The violet colour is focussed nearest to the lens and the red farthest. This defect is known as chromatic aberration.

Prism

It is a homogeneous transparent medium bounded by two plane surfaces inclined at an angle A with each other. These surfaces are called as refracting surfaces and the angle between them is called angle of prism A.
A ray of light suffers two refractions at two surfaces on passing through a prism.

Prism formula is given as $\mu=\frac{\sin[(A+\delta_m)/2]}{\sin(A/2)}$

where δ_m is the minimum deviation.
Angle of deviation, $\delta=(\mu-1)A$



Dispersion

Dispersion of light is the phenomenon of splitting of white light into its constituent colours on passing through a prism. This is because different colours have different wavelengths.

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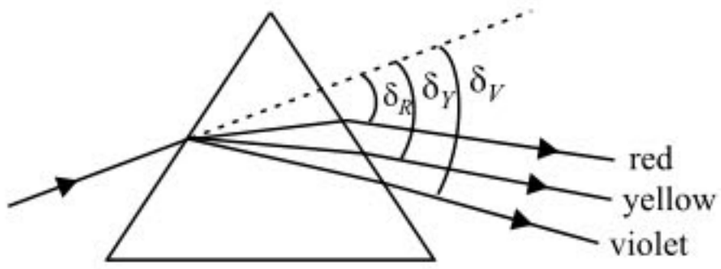


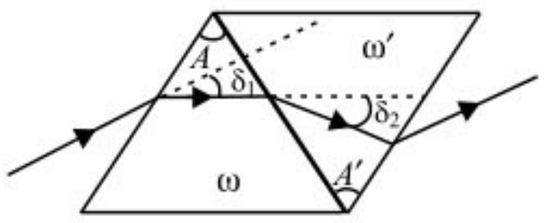
Angular dispersion: Difference in deviation between any two colours is called angular dispersion. $\delta_V - \delta_R = (\mu_V - \mu_R)A$, where μ_V and μ_R represents refractive index for violet and red lights.

Dispersive power, $\omega = \dfrac{\mu_V - \mu_R}{\mu - 1}$, where $\mu = \dfrac{\mu_V + \mu_R}{2}$ is the mean refractive index.

Dispersion without deviation: Two prisms of different materials and different suitable angles can be combined so as to produce only dispersion and no deviation.

Condition for no deviation : $A' = -\dfrac{(\mu - 1)}{(\mu' - 1)}A$

Net angular dispersion, $\theta = \delta(\omega - \omega')$



The prism which produces dispersion without deviation is called 'direct vision prism'.

Deviation without dispersion : In order to produce deviation without dispersion, the two prisms must be placed with their prism angles in opposite directions.

Condition for no dispersion : $A' = -\dfrac{(\mu_V - \mu_R)}{(\mu'_V - \mu'_R)}A$

Net angular deviation $\delta = \delta_1\left[1 - \dfrac{\omega}{\omega'}\right]$

The prism which produces deviation without dispersion is called "achromatic prism".

Spectra

Spectra obtained from luminous bodies are called emission spectra. These are of three types.

- **Line spectrum :** It consists of narrow bright lines separated by dark intervals.
- **Band spectrum :** It consists of a number of bright bands separated by dark intervals and contains a large number of close lines.
- **Continuous spectrum :** A continuous spectrum consists of an unbroken sequence of wavelength over a wide range.

When white light passes through a semi-transparent solid, liquid or gas its spectrum contains certain dark lines or bands, showing that certain wavelengths have been absorbed. Such a spectra is called the absorption spectrum.

Scattering of Light

Changing direction by light because of the presence of number of particles of a typical size present in its path is called scattering of light.

Rayleigh scattering is proportional to fourth power of $1/\lambda$.

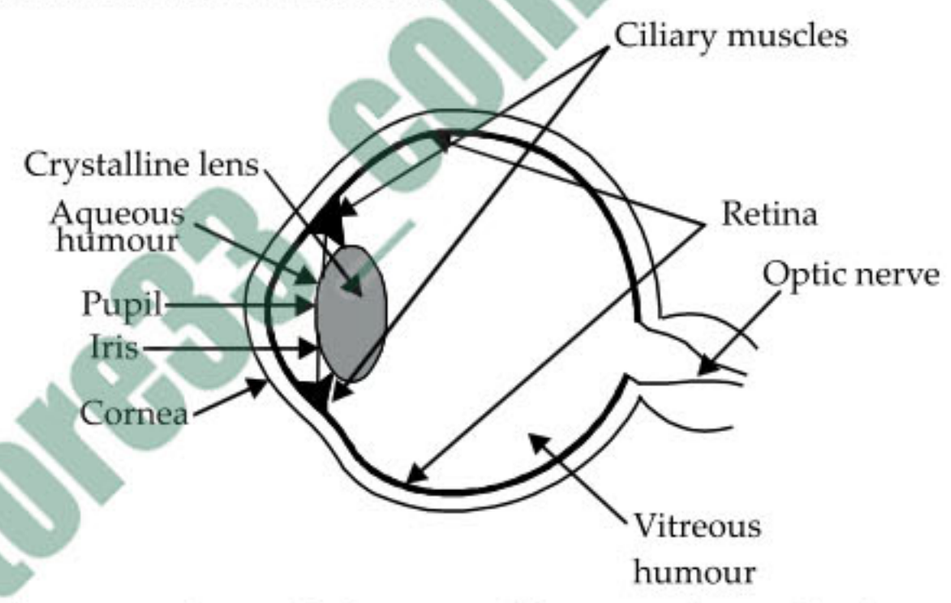
It occurs if the relative size of the scatterer is much smaller than the wavelength of light (λ).

Illustration of scattering of light:

- Blue colour of sky.
- Red colour as signals of danger.
- Red colour at the time of sun-rise and sun-set.
- Black colour of sky in the absence of atmosphere.

Human Eye

Eye is one of the most important optical biological instrument fitted within us.

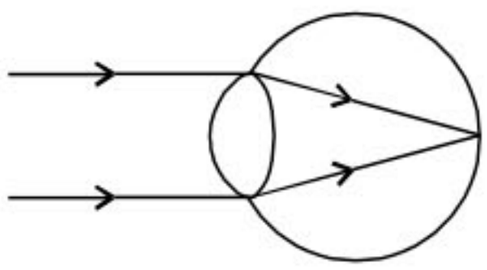


Light enters through the curved front surface called cornea. Then it passes through the pupil which is the central hole in iris. The size of pupil can change under control of muscles. Thus, amount of light or intensity of light entering the eye is controlled by the size of pupil.

Ciliary muscles control the curvature of the lens in the eye and change the effective focal length of crystalline lens of the eye. When muscles are fully relaxed, focal length is maximum which decreases when muscles are strained.

Light is focused by the eye lens on the retina. The retina is a film of nerve fibres covering the curved back surface of the eye. It contains cells in the shapes of rods and cones, which sense light intensity and colour respectively, and transmit electric signals via the optic nerve to the brain which finally process this information.

Focal length of eye lens is maximum when ciliary muscles are fully relaxed and is equal to the distance between eye lens and retina i.e., 2.5 cm for a grown up person.



So, when $u_{max} = \infty$ and $v = +2.5$ cm

Then $\dfrac{1}{f_{max}} = \dfrac{1}{v} - \dfrac{1}{u_{max}} = \dfrac{1}{2.5} - \dfrac{1}{\infty} = \dfrac{1}{2.5} - 0 = \dfrac{1}{2.5}$

or $f_{max} = +2.5$ cm

The closest distance for which the lens can focus light on the retina is called the least distance of distinct vision D, or

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the near point, which is 25 cm for normal vision. So, focal length of eye lens is minimum when ciliary muscles are fully strained and object is at near point.

So, when $u_{min} = -25$ cm and $v = +2.5$ cm

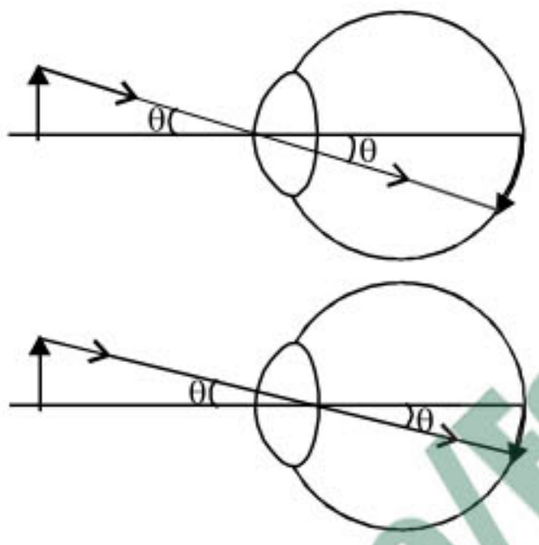
Then $$\frac{1}{f_{min}} = \frac{1}{v} - \frac{1}{u_{min}} = \frac{1}{2.5} + \frac{1}{25} = \frac{11}{25}$$

or $$f_{min} = \frac{25}{11} = +2.27 \text{ cm}$$

So, focal length of eye lens can change within the range of 2.27 cm to 2.5 cm by the action of ciliary muscles, in order to maintain the same image distance (2.5 cm). This property of eye is called accommodation. The ability of the eye by virtue of which it can adjust its focal length to see objects at infinity to at a closest distance of 25 cm from it, is called power of accommodation.

Visual angle

Visual angle is the angle subtended by the object at the eye lens.



Size of the object, as observed by the eye depends upon the visual angle. When the object is close, visual angle is large and object appears large. When object is far, visual angle is small and same object appears to be smaller. Visual angle is maximum when the object is at the least distance of distinct vision D.

Resolving power

Resolving power of eye is the reciprocal of the smallest angle θ subtended by two close objects, so that they appear separately visible, when observed through the eye. This angle θ is called limit of resolution of eye and is less than 1 minute or 1/60°.

Persistence of vision

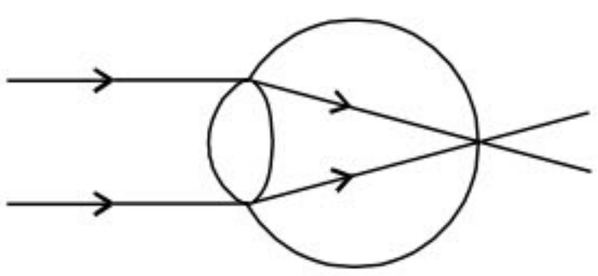
If the time interval between two consecutive light pulses is less than 1/16 s, then eye cannot distinguish between them and the light pulses are then observed to be continuous. This is called persistence of vision.

Defects of eye

Defects of eye are mainly of four types:

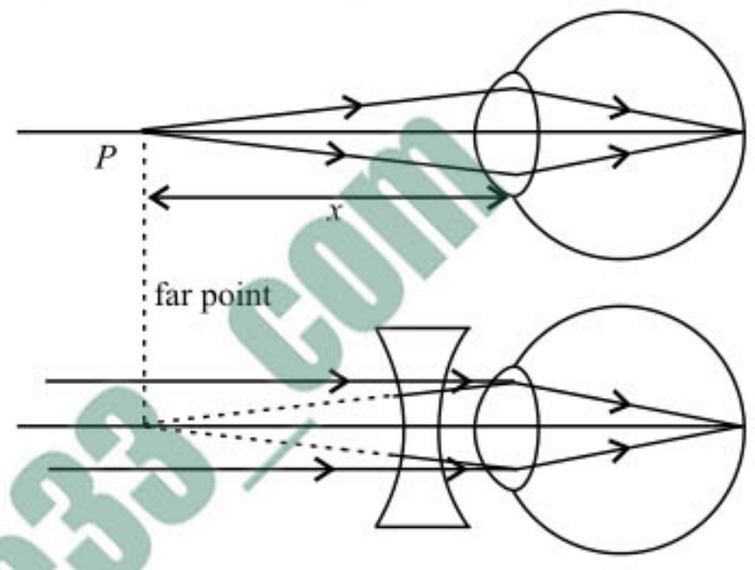
- Myopia
- Hypermetropia
- Presbyopia and
- Astigmatism

(a) Myopia or Near Sightedness : In this defect of eye, the eye lens becomes too thick and cannot focus the image of distant objects on the retina, due to which eye is not able to observe distant objects clearly. In this defect, lens converges incident light of distant object to a point well before the retina, and maximum focal length is less than distance between lens and the retina *i.e.*, less than 2.5 cm.



Far point P of a myopic eye is the farthest distance of the object from the eye, of which clear image is focused on retina.

This defect is removed by introducing an appropriate concave lens between the eye and the object.



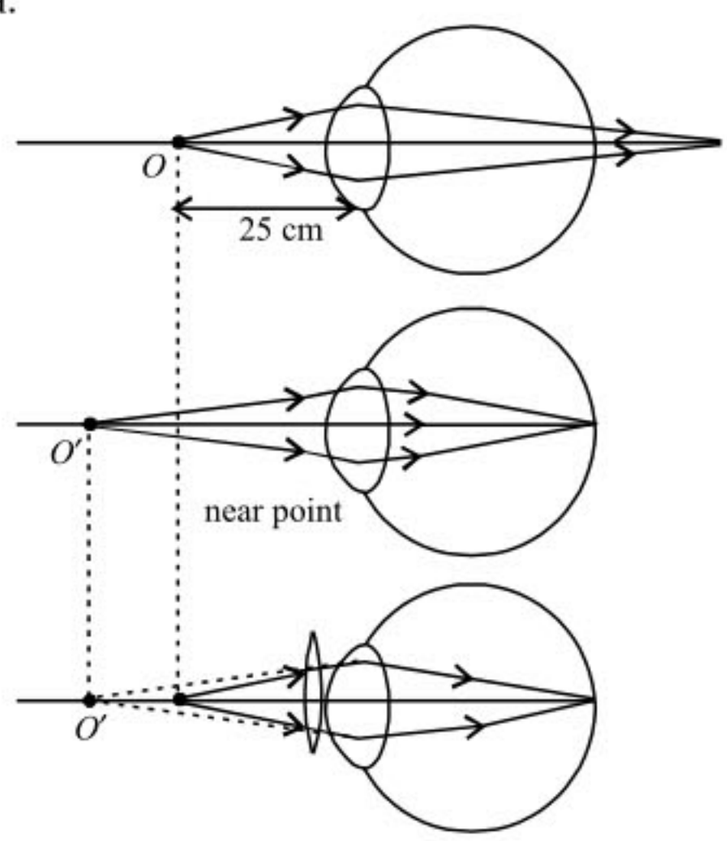
So, for $u = -\infty$, $v = -x$

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \frac{1}{-x} - \frac{1}{\infty} = -\frac{1}{x} + 0 \quad \text{or} \quad f = -x \text{ m}$$

This gives the focal length and $P = -\frac{1}{x}$ D gives the power of the concave lens required to correct the defect of the given myopic eye.

(b) Hypermetropia (Far sightedness) : In this defect the eye lens becomes too thin and cannot focus the image of nearby objects on the retina, due to which eye is not able to observe nearby objects clearly. In this defect, eye converges incident light of nearby object to a point behind the retina, and minimum focal length is more than distance between the lens and the retina *i.e.*, more than 2.5 cm.

Near point D of a hypermetropic eye is the closest distance of the object from the eye, of which clear image is focused on retina.



This defect is removed by interposing an appropriate convex lens between the eye and the object.

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If the near point is at a distance y from the eye lens, then the incident rays from the object at the least distance of distinct vision (25 cm), appear to be coming from near D, after converging from convex lens. So, for $u = -0.25$ m, $v = -y$ m

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} = -\frac{1}{y} + \frac{1}{0.25} = -\frac{1}{y} + 4$$

$$\text{or} \quad f = \frac{y}{4y-1} \text{ m}$$

This gives the power, $P = \frac{4y-1}{y}$ D and it gives the power of the convex lens required to correct the defect of the given hypermetropic eye.

(c) Presbyopia : It is an old age disease. At old age, ciliary muscles loose their elasticity and cannot change the focal length of eye lens effectively. Due to this eye lens looses its power of accommodation, and person can then suffer from both myopia and hypermetropia.

This is overcome either by using two separate spectacles, one for myopia and another for hypermetropia or by using a single spectacle having bifocal lens.

(d) Astigmatism : It is the defect of eye which occurs when the cornea is not spherical in shape. For example, if the cornea have a larger curvature in the vertical plane than in the horizontal plane, then on looking at a horizontal line, focusing in the vertical plane is needed for a sharp image. But due to astigmatism, lines in one direction are well focused, while those in perpendicular direction are not. It is corrected by a lens with one cylindrical surface.

A cylindrical surface focuses rays in one plane but not in a perpendicular plane. By choosing the radius of curvature and axis direction of the cylindrical surface, astigmatism can be corrected. Astigmatism can occur along with myopia or hypermetropia.

Microscope

It is also known as magnifying glass or simple magnifier. It consists of a convergent lens with object between its focus and optical centre and eye close to it. The image formed by it is erect, virtual, enlarged and on same side of lens between object and infinity.

Magnifying power

$$M = \frac{\text{angle subtended by image at the eye}}{\text{angle subtended by the object at the eye}}$$

$$= \frac{\tan\beta}{\tan\alpha} = \frac{\beta}{\alpha}$$

where both the object and image are situated at the least distance of distinct vision.

When the image is formed at infinity (far point),

$$M = \frac{D}{f}$$

When the image is formed at the least distance of distinct vision D (near point), $M = 1 + \frac{D}{f}$

Compound Microscope

It consists of two convergent lenses of short focal lengths and apertures arranged co-axially. Lens (of focal length f_o) facing the object is known as objective or field lens while the lens (of focal length f_e) facing the eye, is known as eye-piece. The objective has a smaller aperture and smaller focal length than eye-piece.

Magnifying power of a compound microscope

$M = m_o \times m_e$

When the final image is formed at infinity (normal adjustment),

$$M = \frac{v_o}{u_o}\left(\frac{D}{f_e}\right)$$

Length of tube, $L = v_o + f_e$

When the final image is formed at least distance of distinct vision,

$$M = \frac{v_o}{u_o}\left(1 + \frac{D}{f_e}\right)$$

where u_o and v_o represent the distance of object and image from the objective lens, f_e is the focal length of an eye lens.

Length of the tube, $L = v_o + \left(\frac{f_e D}{f_e + D}\right)$

Astronomical Telescope (Refracting type)

It consists of two converging lenses. The one facing the object is known as objective or field lens and has large focal length and aperture while the other facing the eye is known as eye-piece or ocular has small focal length and aperture.

When the final image is formed at infinity (normal adjustment), $M = \frac{f_o}{f_e}$

Length of tube, $L = f_o + f_e$

When the final image is formed at least distance of distinct vision, $M = \frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)$

Length of tube, $L = f_o + \frac{f_e D}{f_e + D}$

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EXAM DRILL

1. A convex lens of focal length x and a concave lens of focal length y are placed in contact. The focal length of the combination is

(a) $(x + y)$ (b) $(x - y)$

(c) $\frac{xy}{y-x}$ (d) $\frac{xy}{y+x}$

2. A real image of half the size is obtained in a concave spherical mirror with a radius of curvature of 40 cm. The distance of object and its image will be

(a) 30 cm and 60 cm (b) 60 cm and 30 cm

(c) 15 cm and 30 cm (d) 30 cm and 15 cm

3. A luminous object is placed at a distance of 30 cm from a convex lens of focal length 20 cm. On the other side of the lens, at what distance from the lens must a convex mirror of radius of curvature 10 cm be placed in order to have an upright image of the object coincident with it ?

(a) 12 cm (b) 30 cm

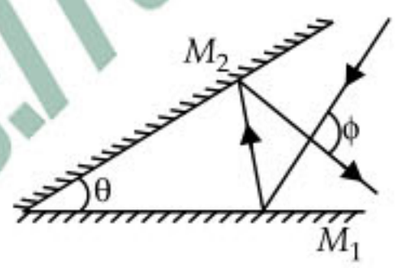
(c) 50 cm (d) 60 cm

4. A convex lens and a concave lens, each having same focal length of 25 cm are put in contact to form a combination of lenses. The power in diopters of the combination is

(a) zero (b) 25

(c) 50 (d) infinite

5. The reflecting surfaces of two mirrors M_1 and M_2 are at an angle θ (angle θ between 0° and 90°) as shown in the figure. A ray of light is incident on M_1.



The emerging ray intersects the incident ray at an angle ϕ. Then,

(a) $\phi = \theta$ (b) $\phi = 180° - \theta$

(c) $\phi = 90° - \theta$ (d) $\phi = 180° - 2\theta$

6. A compound microscope has an eye piece of focal length 10 cm and an objective of focal length 4 cm. Calculate the magnification, if an object is kept at a distance of 5 cm from the objective, so that the final image is formed at the least distance of distinct vision 20 cm.

(a) 12 (b) 11

(c) 10 (d) 13

7. A spherical mirror forms diminished virtual image of magnification 1/3. Focal length is 18 cm. The distance of the object is

(a) 18 cm (b) 36 cm

(c) 48 cm (d) infinite

8. A point source of light is placed 4 m below the surface of water of refractive index 5/3. The minimum diameter of a disc, which should be placed over source, on surface of water to cut off all light coming out of water is

(a) 1 m (b) 4 m

(c) 3 m (d) 6 m

9. A ray of light is incident at an angle of 60° on one face of a prism of angle 30°. The emergent ray of light makes an angle of 30° with incident ray. The angle made by emergent ray with second face of prism will be

(a) 0° (b) 90°

(c) 45° (d) 30°

10. An object is placed on the axis of a convex lens. Its image is formed 80 cm from the object. The magnification is 3. The focal length of the lens is

(a) 45 cm (b) 40 cm

(c) 20 cm (d) 15 cm

11. When the angle of incidence on a material is 60°, the reflected light is completely polarised. The velocity of the refracted ray inside the material is (in m s^{-1})

(a) 3×10^8 (b) $\left(\frac{3}{\sqrt{2}}\right) \times 10^8$

(c) $\sqrt{3} \times 10^8$ (d) 0.5×10^8

12. Two lenses are placed in contact with each other and the focal length of combination is 80 cm. If the focal length of one is 20 cm, then the power of the other will be

(a) 1.66 D (b) 4.00 D

(c) –1.00 D (d) –3.75 D

13. At what distance from a convex lens of focal length 30 cm an object should be placed, so that the size of image be $1/4^{th}$ of the object?

(a) 30 cm (b) 60 cm

(c) 15 cm (d) 150 cm

14. An object is placed at a distance of 10 cm from a concave mirror of radius of curvature 0.6 m. Which of the following statements is incorrect?

(a) The image is formed at a distance of 15 cm from the mirror.

(b) The image formed is virtual.

(c) The image is 0.5 times the size of the object

(d) The image is 1.5 times the size of the object.

15. An achromatic convergent doublet of two lenses in contact has a power of + 2 D. The convex lens has power + 5 D. What is the ratio of the dispersive powers of the convergent and divergent lenses ?

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(a) 2 : 5 (b) 3 : 5
(c) 5 : 2 (d) 5 : 3

16. The focal lengths of the objective and eye lenses of a telescope are respectively 200 cm and 5 cm. The maximum magnifying power of the telescope will be
(a) –40 (b) –48
(c) –60 (d) –100

17. A ray of light is incident normally on one of the faces of a prism of apex angle 30° and refractive index $\sqrt{2}$. The angle of deviation of the ray is
(a) 0° (b) 12.5°
(c) 15° (d) 22.5°

18. A glass prism of refractive index 1.5 is immersed in water $\left(\mu = \frac{4}{3}\right)$. Refer figure.

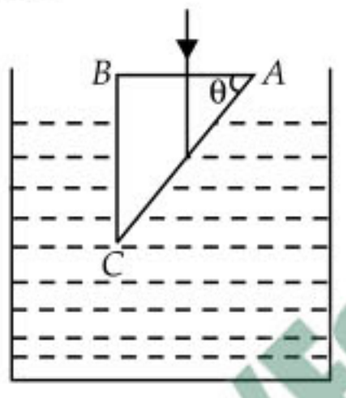
A light beam incident normally on the face *AB* is totally reflected to reach the face *BC* if

(a) $\sin\theta \le \frac{2}{3}$

(b) $\cos\theta \ge \frac{8}{9}$

(c) $\sin\theta > \frac{8}{9}$

(d) $\cos\theta \le \frac{8}{9}$



19. A telescope, whose objective lens has an aperture of 1 mm for the wavelength of light 500 Å, then limiting resolving power of the telescope is
(a) 2.1×10^{-5} rad (b) 4.1×10^{-5} rad
(c) 5.1×10^{-5} rad (d) 6.1×10^{-5} rad

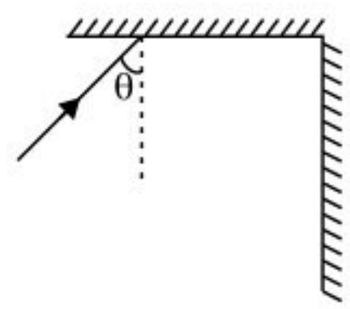
20. A double convex thin lens made out of glass (refractive index, $\mu = 1.5$) has both radii of curvature of magnitude 20 cm. Incident light rays parallel to the axis of the lens will converge at a distance *d* cm such that
(a) $d = 10$ (b) $d = 20/3$
(c) $d = 40$ (d) $d = 20$

21. A bulb is placed at a depth of $2\sqrt{7}$ m in water ($\mu_w = 4/3$) and a floating opaque disc is placed over the bulb so that the bulb is not visible from the surface. What is the minimum diameter of the disc ?
(a) 8 m (b) 12 m
(c) 15 m (d) 20 m

22. The focal length of the lens of refractive index ($\mu = 1.5$) in air is 10 cm. If air is replaced by water of $\mu = \frac{4}{3}$, its focal length is
(a) 20 cm (b) 30 cm
(c) 40 cm (d) 25 cm

23. The nearer point of hypermetropic eye is 40 cm. The lens to be used for its correction should have the power
(a) + 1.5 D (b) – 1.5 D
(c) + 2.5 D (d) + 0.5 D

24. Two plane mirrors are arranged at right angles to each other as shown in figure. A ray of light is incident on the horizontal mirror at an angle θ.



For what value of θ the ray emerges parallel to the incoming ray after reflection from the vertical mirror?
(a) 60° (b) 30°
(c) 45° (d) All of these

25. When a glass prism of refracting angle 60° is immersed in a liquid its angle of minimum deviation is 30°. The critical angle of glass with respect to the liquid medium is
(a) 42° (b) 45°
(c) 50° (d) 52°

26. A person wants to look at his own eye using a concave mirror of radius 40 cm, then the distance between the mirror and the eye should be
(a) 20 cm (b) 30 cm
(c) 40 cm (d) 60 cm

27. Two identical glass $\left(\mu_g = \frac{3}{2}\right)$ equiconvex lenses of focal length *f* are kept in contact. The space between the two lenses is filled with water $\left(\mu_w = \frac{4}{3}\right)$. The focal length of the combination is
(a) f (b) $\frac{f}{2}$
(c) $\frac{4f}{3}$ (d) $\frac{3f}{4}$

28. Match the items in List I with items in List II and select the correct answer from the codes given below the Lists.

	List I		**List II**
I.	Myopia	(A)	Bifocal lens
II.	Hypermetropia	(B)	Cylindrical lens
III.	Presbyopia	(C)	Concave lens
IV.	Astigmatism	(D)	Convex lens

Codes
(a) I-C, II-D, III-A, IV-B
(b) I-D, II-C, III-A, IV-B
(c) I-A, II-B, III-C, IV-D
(d) I-B, II-D, III-A, IV-C

29. A compound microscope has an eye piece of focal length 10 cm and an objective of focal length 4 cm. Calculate the magnification, if an object is kept at a distance of 5 cm from the objective, so that the final image is formed at the least distance of distinct vision 25 cm.

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(a) 12 (b) 11
(c) 13 (d) 14

30. A ray of light travelling in a transparent medium of refractive index μ, falls on a surface separating the medium from air at an angle of incidence of 45°. For which of the following value of μ the ray can undergo total internal reflection?
(a) $\mu = 1.33$ (b) $\mu = 1.40$
(c) $\mu = 1.50$ (d) $\mu = 1.25$

31. A boy of height 1 m stands in front of a convex mirror. His distance from the mirror is equal to its focal length. The height of his image is
(a) 0.25 m (b) 0.33 m
(c) 0.5 m (d) 0.67 m

32. An object is placed 40 cm in front of a convex mirror of radius of curvature 20 cm. The image
(a) is real and 8 cm behind the mirror
(b) is real and 8 cm in front of the mirror
(c) is virtual and 8 cm in front of the mirror
(d) is virtual and 8 cm behind the mirror

33. A beaker contains water up to a height h_1 and kerosene of height h_2 above water so that the total height of (water + kerosene) is $(h_1 + h_2)$. Refractive index of water is μ_1 and that of kerosene is μ_2. The apparent shift in the position of the bottom of the beaker when viewed from above is
(a) $\left(1-\frac{1}{\mu_1}\right)h_2+\left(1-\frac{1}{\mu_2}\right)h_1$
(b) $\left(1+\frac{1}{\mu_1}\right)h_1-\left(1+\frac{1}{\mu_2}\right)h_2$
(c) $\left(1-\frac{1}{\mu_1}\right)h_1+\left(1-\frac{1}{\mu_2}\right)h_2$
(d) $\left(1+\frac{1}{\mu_1}\right)h_2-\left(1+\frac{1}{\mu_2}\right)h_1$

34. The focal length of the lenses of an astronomical telescope are 50 cm and 5 cm. The length of the telescope when the image is formed at the least distance of distinct vision is
(a) 45 cm (b) 55 cm
(c) $\frac{275}{6}$ cm (d) $\frac{325}{6}$ cm

35. In a compound microscope, the focal lengths of two lenses are 1.5 cm and 6.25 cm. If an object is placed at 2 cm from objective and the final image is formed at 25 cm from eye lens, the distance between the two lenses is
(a) 6.00 cm (b) 7.75 cm
(c) 9.25 cm (d) 11.0 cm

36. The refracting angle of a prism is A and the refractive index of the material of the prism is $\cot(A/2)$. The angle of minimum deviation of the prism is
(a) $\pi + 2A$ (b) $\pi - 2A$
(c) $\frac{\pi}{2} + A$ (d) $\frac{\pi}{2} - A$

37. A ray of light is incident normally on one face of a right angled isosceles prism. It then emerges parallel to this face. The refractive index of the material of the prism is
(a) 1.33 (b) 1.414
(c) 1.5 (d) 1.732

38. A person wants a real image of his own, 3 times enlarged. Where should he stand before a concave mirror of radius of curvature 30 cm?
(a) 10 cm (b) 30 cm
(c) 90 cm (d) 20 cm

39. A metal plate is lying at the bottom of a tank full of a transparent liquid. Height of tank is 100 cm but the plate appears to be at 45 cm above bottom. The refractive index of liquid is
(a) 1.00 (b) 1.53
(c) 1.81 (d) 1.32

40. A ray of light when falls on a liquid A – air interface at angle 45°, it just gets total reflection. When a ray of light falls on liquid B – air interface at angle 30°, it does not emerge out. We can infer that
(a) $\mu_A > \mu_B$
(b) $\mu_A < \mu_B$
(c) $\mu_A = \mu_B$
(d) can't be inferred

41. A ray of light falls on a glass slab making an angle of 45° with normal. The emergent ray makes the same angle with normal. It shows that
(a) there is no refraction taking place
(b) incident ray is perpendicular to emergent ray
(c) emergent ray is parallel to the incident ray
(d) the given case is not possible.

42. Two thin convex lenses of focal length 20 cm and 25 cm are placed at a finite distance apart. The power of the combination is 8 D. Distance between the lenses is
(a) 5 cm (b) 10 cm
(c) 8 cm (d) 4 cm

43. When a ray of light falls on a prism of angle 48°, it suffers minimum deviation. Refractive index of the material of prism is 1.6. The angle of incidence is nearly
(a) 16° (b) 48°
(c) 30° (d) 41°

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44. A beam of light travelling in water falls on a glass plate immersed in water. When the incident angle is 51°, the reflected beam of light is found to be completely plane polarised. The refractive index of glass is
(Given refractive index of water = 4/3)
(a) 1.091 (b) 2.312
(c) 1.647 (d) 5.734

45. A converging lens is used to form an image on a screen. When the upper half of the lens is covered by an opaque screen, then
(a) half the image will disappear
(b) no image will be formed
(c) intensity of image will decrease
(d) intensity of image will increase

DAY 23 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____
(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (c) : The focal length of combination is

$$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}=\frac{1}{x}-\frac{1}{y}=\frac{y-x}{xy}$$

$$f=\frac{xy}{y-x}$$

2. (b) : Since the image is real,

$\therefore \quad m=-\frac{v}{u}=-\frac{1}{2}$ or $u=2v$

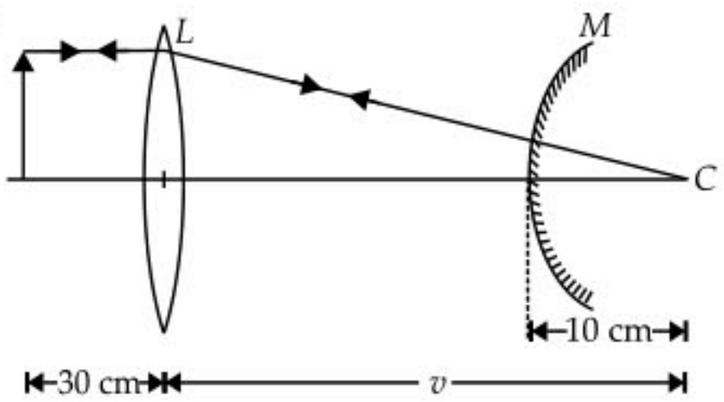
$\therefore \quad R=40\text{ cm} \Rightarrow f=-20\text{ cm}$

As $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$

$\therefore \quad \frac{1}{v}+\frac{1}{2v}=\frac{1}{-20}$ or $\frac{3}{2v}=-\frac{1}{20}$ or $v=-30\text{ cm}$

or $u=2v=-60\text{ cm}$

3. (c) :



This is possible when the rays are incident on the mirror normally, *i.e.*, the image by the lens is formed at the centre of curvature of the mirror.

Now, $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$ or $\frac{1}{20}=\frac{1}{v}+\frac{1}{30}$

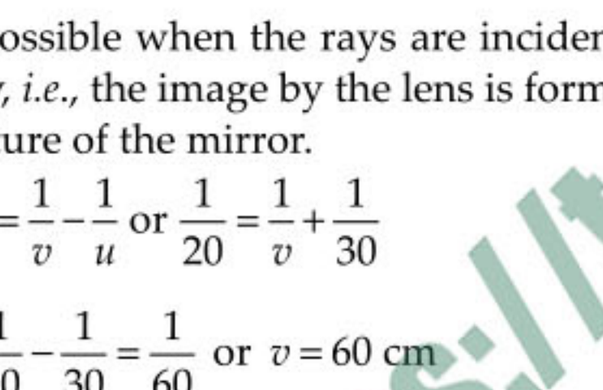
$\therefore \quad \frac{1}{v}=\frac{1}{20}-\frac{1}{30}=\frac{1}{60}$ or $v=60\text{ cm}$

From figure, the distance of mirror from lens is,
$LM=LC-MC=60-10=50\text{ cm}$

4. (a) : Focal length of convex lens, $f_1=25$ cm
Focal length of concave lens, $f_2=-25$ cm
Power of combination in diopters,

$$P=P_1+P_2=\frac{100}{f_1}+\frac{100}{f_2}=\frac{100}{25}-\frac{100}{25}=0$$

5. (d) :



Let i_1 be the angle of incidence on mirror M_1 and i_2 be the angle of incidence on mirror M_2
In ΔACB
$90^\circ-i_1+\theta+90^\circ-i_2=180^\circ$
or $\quad i_1+i_2=\theta \qquad \ldots$ (i)

In ΔACD
$2i_1+2i_2+\phi=180^\circ$
$\phi=180^\circ-2(i_1+i_2)=180^\circ-2\theta$ (Using (i))

6. (a) : Here, $u_o=-5$ cm, $f_o=4$ cm,
$f_e=10$ cm, $D=20$ cm
According to lens formula

$$\frac{1}{v_o}-\frac{1}{u_o}=\frac{1}{f_o} \quad \text{or} \quad \frac{1}{v_o}=\frac{1}{f_o}+\frac{1}{u_o}$$

Substituting the given values, we get

$$\frac{1}{v_o}=\frac{1}{4}+\frac{1}{-5}=\frac{1}{4}-\frac{1}{5}=\frac{1}{20}$$

$v_o=20$ cm

Magnification, $M=\frac{v_o}{|u_o|}\left(1+\frac{D}{f_e}\right)$

$$=\frac{20}{5}\left(1+\frac{20}{10}\right)=12$$

7. (b) : Here, the given mirror is a convex mirror.

As, $m=\frac{f}{f-u}$

or $\frac{1}{3}=\frac{18}{18-u}$ or $3\times18=18-u$ or $u=-36$ cm

8. (d) : Here $\sin C=\frac{1}{\mu}=\frac{1}{5/3}=\frac{3}{5} \quad \therefore \quad \tan C=\frac{3}{4}$

If R is radius of disc, then $\tan C=\frac{R}{h}$,

$$R=h\tan C=4\times\frac{3}{4}=3\text{ m}$$

Diameter of disc $=2R=6$ m

9. (b) : Here, $i_1=60^\circ$, $A=30^\circ$, $\delta=30^\circ$, $i_2=?$
As $i_1+i_2=A+\delta$
$\therefore \quad i_2=A+\delta-i_1=30^\circ+30^\circ-60^\circ=0^\circ$
Angle of emergent ray with second face of prism
$=90^\circ-0^\circ=90^\circ$

10. (d)

11. (c) : From Brewster's law,
$\mu=\tan i_p$

or $\quad \frac{c}{v}=\tan 60^\circ$

$\therefore \quad v=\frac{3\times10^8}{\sqrt{3}}=\sqrt{3}\times10^8\text{ m s}^{-1}$

12. (d) : Focal length of the combination,

$$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2} \Rightarrow \frac{1}{80}=\frac{1}{20}+\frac{1}{f_2}$$

$\therefore \quad f_2=-\frac{80}{3}\text{cm}$

$\therefore$ Power of second lens $P'=\frac{100}{f_2}=\frac{100}{(-80/3)}=-3.75\text{D}$

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13. (d) : Image is real.

$$\therefore \quad m = \frac{v}{u} = -\frac{1}{4} \quad \text{or} \quad v = -\frac{u}{4}$$

As $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

$$\therefore \quad \frac{1}{(-u/4)} - \frac{1}{u} = \frac{1}{30}$$

$$-\frac{4}{u} - \frac{1}{u} = \frac{1}{30}$$

or $u = -150$ cm

14. (c) : Here $f = -\frac{0.6}{2} = -0.3 \text{ m} = -30 \text{ cm}, u = -10 \text{ cm}$

As, $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$ or $\frac{1}{v} + \frac{1}{-10} = \frac{1}{-30}$

$$\frac{1}{v} = \frac{1}{10} - \frac{1}{30} = \frac{3-1}{30} \quad \text{or} \quad v = \frac{30}{2}\text{cm} = 15 \text{ cm}$$

$$\therefore \quad m = -\frac{v}{u} = -\frac{15}{-10} = 1.5$$

Object is placed between principal focus and pole. So, the image is virtual and erect.

15. (b) : The condition for achromatism is

$\omega_1 P_1 + \omega_2 P_2 = 0$

$$\omega_1 P_1 = -\omega_2 P_2 \quad \Rightarrow \quad \frac{\omega_1}{\omega_2} = -\frac{P_2}{P_1}$$

Now, $P_1 + P_2 = 2$ D or $5 + P_2 = 2$ or $P_2 = -3$ D

$$\therefore \quad \frac{\omega_1}{\omega_2} = -\frac{-3}{5} = \frac{3}{5}$$

16. (b) : Magnifying power is maximum when image is formed at the least distance of distinct vision.

$$M = -\frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right) = -\frac{200}{5}\left(1 + \frac{5}{25}\right) = -48$$

17. (c) : For normal incidence,

$i_1 = 0, r_1 = 0$

As, $r_1 + r_2 = A \quad \therefore \quad r_2 = A - r_1 = 30°$

As $\mu = \frac{\sin i_2}{\sin r_2}$

$$\therefore \quad \sin i_2 = \mu \sin r_2 = \sqrt{2} \sin 30° = \frac{1}{\sqrt{2}} \quad \therefore \quad i_2 = 45°$$

or $\delta = i_1 + i_2 - A = 0 + 45° - 30° = 15°$

18. (c) : Here, ${}^a\mu_g = 1.5 = \frac{3}{2}, {}^a\mu_w = \frac{4}{3}$

${}^a\mu_w \times {}^w\mu_g = {}^a\mu_g$

$$\therefore \quad {}^w\mu_g = \frac{{}^a\mu_g}{{}^a\mu_w} = \frac{3/2}{4/3} = \frac{9}{8}$$

As $\sin C = \frac{1}{{}^w\mu_g} = \frac{1}{9/8} = \frac{8}{9}$

$$C = \sin^{-1}\left(\frac{8}{9}\right)$$

For total internal reflection, $\theta > C$

$$\theta > \sin^{-1}\left(\frac{8}{9}\right) \quad \text{or} \quad \sin\theta > \frac{8}{9}$$

19. (d) : Given:

Aperture of objective lens (a) = 1 mm = 1×10^{-3} m

Wavelength of light (λ) = 500 Å = 500×10^{-10} m

Limiting resolving power of telescope,

$$d\theta = \frac{1.22\lambda}{a} = \frac{1.22 \times 500 \times 10^{-10}}{1 \times 10^{-3}} = 6.1 \times 10^{-5} \text{ rad}$$

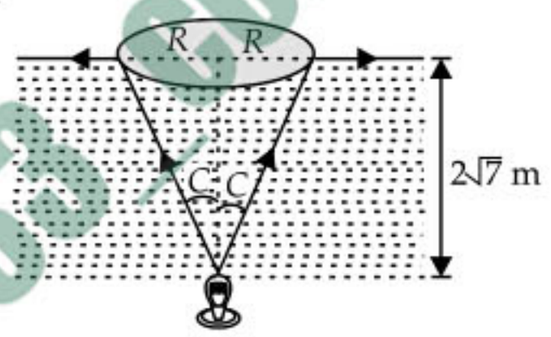
20. (d) : Here, $f = d$, $R_1 = +20$ cm, $R_2 = -20$ cm

$$\frac{1}{f} = (\mu - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \quad \Rightarrow \quad \frac{1}{d} = (1.5 - 1)\left[\frac{1}{20} - \frac{1}{-20}\right]$$

$$\frac{1}{d} = 0.5 \times \frac{2}{20} \quad \therefore \quad d = 20 \text{ cm}$$

21. (b) : Here, refractive index of water, $\mu_w = \frac{4}{3}$

$$\sin C = \frac{1}{\mu_w} = \frac{3}{4} \qquad ...(i)$$



From figure,

$$\sin C = \frac{R}{\sqrt{R^2 + (2\sqrt{7})^2}} \qquad ...(ii)$$

Equating (i) and (ii), we get

$$\frac{3}{4} = \frac{R}{\sqrt{R^2 + (2\sqrt{7})^2}}$$

Squaring both sides, we get

$$\frac{9}{16} = \frac{R^2}{R^2 + 28} \quad \Rightarrow \quad 9R^2 + 28 \times 9 = 16R^2$$

$$7R^2 = 28 \times 9$$

$$R^2 = \frac{28 \times 9}{7} = 36 \quad \Rightarrow \quad R = 6 \text{ m}$$

Hence, the minimum diameter of the disc is

$2R = 2 \times 6$ m = 12 m

22. (c) : According to lens maker's formula,

The focal length of the lens in air is

$$\frac{1}{f_{air}} = \left(\frac{\mu_l}{\mu_a} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \left(\frac{3/2}{1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{f_{air}} = \frac{1}{2}\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ...(i)$$

The focal length of the lens in water is

$$\frac{1}{f_{water}} = \left(\frac{\mu_l}{\mu_w} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \left(\frac{3/2}{4/3} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{f_{water}} = \frac{1}{8}\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ...(ii)$$

Divide (i) by (ii), we get

$$\frac{f_{water}}{f_{air}} = 4$$

$f_{water} = 4 \times f_{air} = 4 \times 10$ cm = 40 cm

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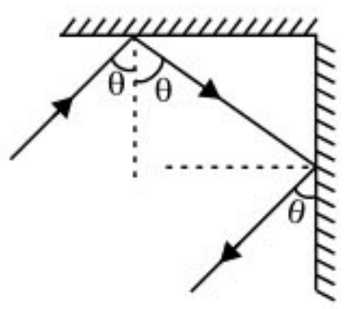
23. (c) : Hypermetropia is corrected by using convex lens.

Focal length of lens used, $f = +$(defected near point)

$$f = +d = +40 \text{ cm}$$

$$\therefore \text{ Power of lens} = \frac{100}{f(\text{cm})} = \frac{100}{+40} = +2.5 \text{ D}$$

24. (d) : The incident and the second reflected ray make the same angle θ with vertical. Therefore, they are parallel for any value of θ.



25. (b) : Here, $A = 60°$, $\delta_m = 30°$

$$^{\ell}\mu_g = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

$$^{\ell}\mu_g = \frac{\sin\left(\frac{60°+30°}{2}\right)}{\sin\left(\frac{60°}{2}\right)} = \frac{\sin 45°}{\sin 30°} = \sqrt{2}$$

Let C be the critical angle of glass with respect to the liquid medium.

$$\therefore \quad \sin C = \frac{1}{^{\ell}\mu_g} = \frac{1}{\sqrt{2}} \text{ or } C = \sin^{-1}\left(\frac{1}{\sqrt{2}}\right) = 45°$$

26. (c)

27. (d) : Let R be the radius of curvature of each surface.

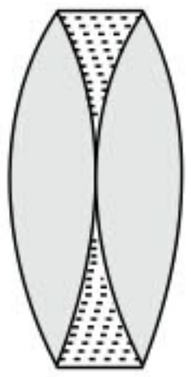
$$\frac{1}{f} = (1.5-1)\left(\frac{1}{R}+\frac{1}{R}\right) \qquad \therefore \quad R = f$$

For the water lens, $\frac{1}{f'} = \left(\frac{4}{3}-1\right)\left(-\frac{1}{R}-\frac{1}{R}\right) = \frac{1}{3}\left(-\frac{2}{f}\right)$

or $\frac{1}{f'} = -\frac{2}{3f}$

Using, $\frac{1}{F} = \frac{1}{f_1}+\frac{1}{f_2}+\frac{1}{f_3}$,

$$\frac{1}{F} = \frac{1}{f}+\frac{1}{f}+\frac{1}{f'} = \frac{2}{f}-\frac{2}{3f} = \frac{4}{3f} \qquad \therefore \quad F = \frac{3f}{4}$$



28. (a) :

Myopia	Concave lens
Hypermetropia	Convex lens
Presbyopia	Bifocal lens
Astigmatism	Cylindrical lens

29. (d) : Here, $f_o = 4$ cm, $f_e = 10$ cm, $u_o = -5$ cm

For objective

$$\frac{1}{v_o}-\frac{1}{-5} = \frac{1}{4}$$

$$\frac{1}{v_o} = \frac{1}{4}-\frac{1}{5} = \frac{1}{20} \text{ or } v_o = 20 \text{ cm}$$

Magnification when the final image is formed at the least distance of distinct vision D (= 25 cm) is

$$M = \frac{v_o}{|u_o|}\left(1+\frac{D}{f_e}\right) = \frac{20}{5}\left(1+\frac{25}{10}\right) = 14$$

30. (c) : For total internal reflection,

$$\mu \geq \frac{1}{\sin C}$$

$$\mu \geq \frac{1}{\sin 45°} \text{ or } \mu \geq \sqrt{2}(=1.414) \qquad \therefore \quad \mu = 1.5$$

31. (c) : Let f be focal length of the convex mirror.

According to new cartesian sign convention

Object distance, $u = -f$, focal length $= +f$

According to mirror formula

$$\frac{1}{u}+\frac{1}{v} = \frac{1}{f}$$

$$\frac{1}{-f}+\frac{1}{v} = \frac{1}{f} \text{ or } \frac{1}{v} = \frac{1}{f}+\frac{1}{f} = \frac{2}{f} \text{ or } v = \frac{f}{2}$$

The image is formed at a distance $\frac{f}{2}$ behind the mirror. It is a virtual image.

Magnification, $M = -\frac{v}{u} = -\frac{(f/2)}{(-f)} = \frac{1}{2}$

Also, $M = \frac{\text{Height of image}(h_I)}{\text{Height of object}(h_O)}$

$$\therefore \quad h_I = Mh_O = \frac{1}{2}(1 \text{ m}) = 0.5 \text{ m}$$

32. (d) : According to new cartesian sign conventions,

$u = -40$ cm, $R = +20$ cm

$$f = \frac{R}{2} = +10 \text{ cm}$$

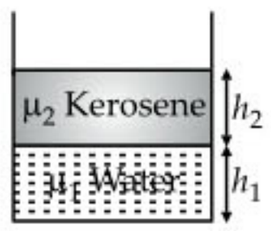
According to mirror formula

$$\frac{1}{u}+\frac{1}{v} = \frac{1}{f} \quad \therefore \quad \frac{1}{-40}+\frac{1}{v} = \frac{1}{10}$$

$$\frac{1}{v} = \frac{1}{10}+\frac{1}{40} = \frac{1}{8} \quad \text{or} \quad v = 8 \text{ cm}$$

The image is formed at 8 cm behind the mirror. It is a virtual image.

33. (c) : Apparent shift of bottom position of beaker in water is



$$x_1 = h_1 - \frac{h_1}{\mu_1} = h_1\left(1-\frac{1}{\mu_1}\right)$$

Apparent shift of bottom position in kerosene is

$$x_2 = h_2 - \frac{h_2}{\mu_2} = h_2\left(1-\frac{1}{\mu_2}\right)$$

$$\text{Total shift} = x_1+x_2 = h_1\left(1-\frac{1}{\mu_1}\right)+h_2\left(1-\frac{1}{\mu_2}\right)$$

34. (d) : Here, $f_o = 50$ cm, $f_e = 5$ cm, $D = 25$ cm

The length of the telescope when the image is formed at the least distance of distinct vision is

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$$L = f_o + \frac{f_e D}{f_e + D} = 50 + \frac{5\times 25}{5+25} = 50 + \frac{25}{6} = \frac{325}{6}\text{ cm}$$

35. (d) : Here, $f_o = 1.5$ cm, $f_e = 6.25$ cm, $u_o = -2$ cm, $v_e = -25$ cm

For objective,

$$\frac{1}{v_o} - \frac{1}{u_o} = \frac{1}{f_o} \quad \therefore \quad \frac{1}{v_o} - \frac{1}{-2} = \frac{1}{1.5}$$

$$\frac{1}{v_o} = \frac{1}{1.5} - \frac{1}{2} \text{ or } v_o = 6\text{ cm}$$

For eye piece

$$\frac{1}{v_e} - \frac{1}{u_e} = \frac{1}{f_e} \Rightarrow \frac{1}{-25} - \frac{1}{u_e} = \frac{1}{6.25}$$

$$-\frac{1}{u_e} = \frac{1}{6.25} + \frac{1}{25} \text{ or } u_e = -5\text{ cm}$$

Distance between two lenses = $|v_o| + |u_e|$
= 6 cm + 5 cm = 11 cm

36. (b) : Here, $\mu = \cot\left(\frac{A}{2}\right)$

According to prism formula

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

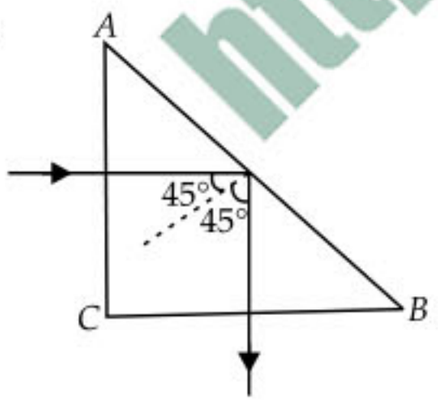
$$\cot\left(\frac{A}{2}\right) = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)} \Rightarrow \frac{\cos\left(\frac{A}{2}\right)}{\sin\left(\frac{A}{2}\right)} = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

$$\cos\left(\frac{A}{2}\right) = \sin\left(\frac{A+\delta_m}{2}\right) \Rightarrow \sin\left(\frac{\pi}{2} - \frac{A}{2}\right) = \sin\left(\frac{A+\delta_m}{2}\right)$$

$$\frac{\pi}{2} - \frac{A}{2} = \frac{A+\delta_m}{2}$$

$\pi - A = A + \delta_m$ or $\delta_m = \pi - 2A$

37. (b) :



As is clear from figure, $C = 45°$

$$\mu = \frac{1}{\sin C} = \frac{1}{\sin 45°} = \sqrt{2} = 1.414$$

38. (a) : Let the object distance be u
$R = -30$ cm or $f = -15$ cm

$$m = \frac{h_I}{h_O} = \frac{-v}{u} = 3 \quad \Rightarrow v = -3u$$

Using mirror formula,

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} \quad \Rightarrow \quad \frac{1}{-15} = \frac{1}{-3u} + \frac{1}{u}$$

$$\text{or} \quad \frac{2}{3u} = \frac{-1}{15} \Rightarrow u = \frac{-2\times 15}{3} = -10\text{ cm}$$

39. (c) : Real depth of plate, $H = 100$ cm
Apparent depth of plate, $h = 100 - 45 = 55$ cm

$\therefore$ Refractive index of fluid = $\frac{H}{h} = \frac{100}{55} = 1.81$

40. (b) : For liquid A – air interface,

$$\mu_A = \frac{1}{\sin i_C} = \frac{1}{\sin 45°} = \sqrt{2}$$

For liquid B – air interface, the ray does not emerge out for $\theta = 30°$ *i.e.*, $i_c \le 30°$

$$\sin i_c \le \sin 30° = \frac{1}{2} \quad \text{or} \quad \frac{1}{\sin i_c} \ge 2 \quad \Rightarrow \quad \mu_B \ge 2$$

41. (c)

42. (a) : Here, $f_1 = 20$ cm, $f_2 = 25$ cm, $P = 8$ D

Focal length of combination $= \frac{1}{8}\text{ m} = \frac{100}{8}\text{ cm}$

Now, using $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$,

(where d is the distance between lenses), we get

$$\frac{8}{100} = \frac{1}{20} + \frac{1}{25} - \frac{d}{20\times 25}$$

$$\Rightarrow \quad \frac{d}{500} = \frac{1}{20} + \frac{1}{25} - \frac{8}{100} = \frac{5+4-8}{100} = \frac{1}{100}$$

$$\text{or} \quad d = \frac{500}{100} = 5\text{ cm}$$

43. (d) : Given, $A = 48°$, $\mu = 1.6$

For minimum deviation, $r = \frac{A}{2}$

According to Snell's law, $\mu = \frac{\sin i}{\sin r}$

$$\text{or } \sin i = \mu \sin r = \mu \sin\frac{A}{2} = 1.6\times \sin\frac{48°}{2} = 1.6\times \sin 24°$$

$= 1.6 \times 0.407 = 0.651$

$\therefore \quad i = \sin^{-1}(0.651) = 40.6° \approx 41°$

44. (c) : Refractive index of glass w.r.t. water,

$${}^{w}\mu_{g} = \tan i_p = \tan 51° = 1.235$$

$$\therefore \quad {}^{a}\mu_{g} = {}^{w}\mu_{g} \times {}^{a}\mu_{w} = 1.235\times\frac{4}{3} = 1.647$$

45. (c) : Image formed is complete but has decreased intensity.

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Wave Optics

Wavefront

A source of light sends the distribution in all the directions and continuous locus of all the particles vibrating in same phase at any instant is called wavefront.

Phase speed is the speed with which a wavefront moved outward from the source.

Wavefront depends on the shape of sources of light, it can be of three types

- **Spherical wavefront :** When the source of light is a point source, the wavefront is spherical.
- **Cylindrical wavefront :** When the source of light is linear, *e.g.* a slit, the wavefront is cylindrical.
- **Plane wavefront :** When the point source or linear source of light is at very large distance, a small portion of spherical or cylindrical wave front appears to be plane. Such a wavefront is known as plane wavefront.

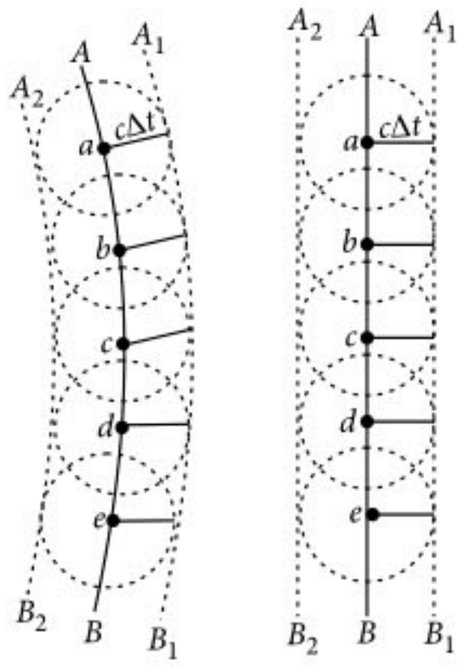
Huygens Principle

According to Huygens principle :

- Each and every point on the given wavefront, called primary wavefront, acts as a source of new disturbances, called secondary wavelets, that travel in all directions with the velocity of light in the medium.
- A surface touching these secondary wavelets tangentially in the forward direction at any instant gives a new wavefront at the instant, which is known as the secondary wavefront.

Let us consider two wavefronts *AB*, shown in figure, for understanding Huygens principle.

Let us assume that *AB* is the primary wavefront at any given instant of time. One of them is a plane wavefront and the other is a curved wavefront. Let us take points *a*, *b*, *c*, *d* and *e* on the two primary wavefronts *AB*. These points act as secondary wavelets. The distance travelled by light in Δt seconds is $c\Delta t$, where c is the speed of light. Now with *a*, *b*, *c*, *d*, and *e* as centre and radius equal to $c\Delta t$, draw circles. Then draw surface A_1B_1 and A_2B_2 touching these dotted circles tangentially as shown in figure. Since light travels in forward direction, wavefront A_1B_1 is the newly formed secondary wavefront. Thus by using Huygens principle, if we know the primary wavefront at any instant, we can calculate the secondary wavefront after instant *t*.



Change in Wavelength and Velocity

The frequency of a wave is the characteristic of its source. Thus it does not change due to medium. Thus the velocity of a wave changes from one medium to another medium due to its change in wavelength. In a medium of absolute refractive index μ, the velocity of wave is $v = \upsilon\lambda'$

where λ' is wavelength in this medium.

In free space, $c = \upsilon\lambda$

$$\therefore \frac{c}{v} = \frac{\upsilon\lambda}{\upsilon\lambda'} \Rightarrow \frac{\lambda}{\lambda'} = \mu \Rightarrow \lambda' = \frac{\lambda}{\mu}$$

Coherent Source

Two monochromatic sources of the same frequency, same wavelength and constant phase relation are said to be coherent.

Interference of Light

It is the phenomenon of redistribution of energy on account of superposition of light waves from two coherent sources. Interference pattern produce points of maximum and minimum intensity. Points where resultant intensity is maximum, interference is said to be constructive and at the points of destructive interference, resultant intensity is minimum.

Conditions for sustained interference of light

The two sources should continuously emit waves of the same wavelength or frequency. The amplitudes of waves from two sources should preferably be equal. The waves emitted by the two sources should either be in phase or should have a constant phase difference. The two sources must lie very close to each other. The two sources should be very narrow.

Intensity distribution

If *a*, *b* are the amplitudes of interfering waves due to two coherent sources and ϕ is constant phase difference between the two waves at any point *P*, then the resultant amplitude at *P* will be

$$R = \sqrt{a^2 + b^2 + 2ab\cos\phi}$$

If $a^2 = I_1$, $b^2 = I_2$, then

Resultant intensity, $I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$

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If $I_1 = I_2 = I_0$, then

$$I = I_0 + I_0 + 2I_0 \cos\phi = 4I_0 \cos^2\frac{\phi}{2}$$

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$$

When $\cos\phi = 1$; $I_{max} = I_1 + I_2 + 2\sqrt{I_1 I_2} = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2$

When $\cos\phi = -1$, $I_{min} = \left(\sqrt{I_1} - \sqrt{I_2}\right)^2$

$$\frac{I_{max}}{I_{min}} = \frac{\left(\sqrt{I_1} + \sqrt{I_2}\right)^2}{\left(\sqrt{I_1} - \sqrt{I_2}\right)^2}$$

If $I_1 = I_2 = I_0$, then, $I_{max} = 4I_0$; $I_{min} = 0$.
If the sources are incoherent, $I = I_1 + I_2$

Young's Double Slit Experiment

Thomas Young was the first to demonstrate the phenomenon of interference of light. Using two slits illuminated by monochromatic light source, he obtained bright and dark bands of equal width placed alternately. These were called interference fringes.

For constructive interference (*i.e.* formation of bright fringes)

- For n^{th} bright fringe,

  path difference $= x_n \frac{d}{D} = n\lambda$

  where $n = 0$ for central bright fringe
  $n = 1$ for first bright fringe,
  $n = 2$ for second bright fringe and so on
  d = distance between the two slits
  D = distance of slits from the screen
  x_n = distance of n^{th} bright fringe from the centre.

  $\therefore \quad x_n = n\lambda\frac{D}{d}$

For destructive interference (*i.e.* formation of dark fringes)

- For n^{th} dark fringe,

  path difference $= x_n \frac{d}{D} = (2n-1)\frac{\lambda}{2}$

  where
  $n = 1$ for first dark fringe,
  $n = 2$ for 2^{nd} dark fringe and so on.
  x_n = distance of n^{th} dark fringe from the centre

  $\therefore \quad x_n = (2n-1)\frac{\lambda}{2}\frac{D}{d}$

Fringe width : The distance between any two consecutive bright or dark fringes is known as fringe width.

Fringe width, $\beta = \frac{\lambda D}{d}$

Angular fringe width, $\theta = \frac{\beta}{D} = \frac{\lambda}{d}$

If W_1, W_2 are widths of two slits, I_1, I_2 are intensities of light coming from two slits; a, b are the amplitudes of light from these slits, then

$$\frac{W_1}{W_2} = \frac{I_1}{I_2} = \frac{a^2}{b^2} \quad \text{or} \quad \frac{I_{max}}{I_{min}} = \frac{(a+b)^2}{(a-b)^2}$$

Fringe visibility, $V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$

When entire apparatus of Young's double slit experiment is immersed in a medium of refractive index μ, then fringe width becomes

$$\beta' = \frac{\lambda' D}{d} = \frac{\lambda D}{\mu d} = \frac{\beta}{\mu}$$

When a thin transparent plate of thickness t and refractive index μ is placed in the path of one of the interfering waves, fringe width remains unaffected but the entire pattern shifts by

$$\Delta x = (\mu - 1)\, t\, \frac{D}{d} = (\mu - 1)\, t\, \frac{\beta}{\lambda}$$

This shifting is towards the side in which transparent plate is introduced.

Colour of thin films

A soap film or a thin film of oil spread over water surface, when seen in white light appears coloured. This effect can be explained in terms of phenomenon of interference.

In the reflected system

- Condition for constructive interference is

  $2\mu t\cos r = (2n-1)\frac{\lambda}{2}$

  where $n = 1, 2, 3,.....$
- Condition for destructive interference is

  $2\mu t\cos r = n\lambda$

  where $n = 0, 1, 2,.....$

In the transmitted system

- Condition for constructive interference is

  $2\mu t\cos r = n\lambda$

  where $n = 0, 1, 2, 3,.....$
- Condition for destructive interference is

  $2\mu t\cos r = (2n-1)\frac{\lambda}{2}$

  where $n = 1, 2, 3,.....$

t = thickness of thin film, μ = refractive index of material of the film, r = angle of refraction, λ = wavelength of light used.

Diffraction of Light

It is the phenomenon of bending of light around corners of an obstacle or aperture in the path of light. On account of this bending, light penetrates into the geometrical shadow of the obstacle. The deviation is more effective when the dimensions of the obstacle or aperture are comparable to the wavelength of light. This is, therefore, the essential condition for diffraction of light.

Diffraction of light is of two types :

- Fresnel diffraction
- Fraunhofer diffraction

Fresnel diffraction : In this case, the source or the screen or both are at finite distances from the aperture or obstacle causing diffraction.

Fraunhofer diffraction : In this case, the source and the screen on which the pattern is observed are at infinite distances from the aperture or the obstacle causing diffraction.

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Diffraction Due to a Single Slit

The diffraction pattern produced by a single slit of width a consists of a central maximum bright band with alternating bright and dark bands of decreasing intensity on both sides of the central maximum.

- Condition for n^{th} secondary maximum is
  Path difference $= a\sin\theta_n = (2n+1)\frac{\lambda}{2}$
  where $n = 1, 2, 3,.....$
- Condition for n^{th} secondary minimum is
  Path difference = $a\sin\theta_n = n\lambda$
  where $n = 1, 2, 3,.....$
- Width of secondary maxima or minima
  $\beta = \frac{\lambda D}{a} = \frac{\lambda f}{a}$
  where
  a = width of slit
  D = distance of screen from the slit
  f = focal length of lens for diffracted light
- Width of central maximum $= \frac{2\lambda D}{a} = \frac{2f\lambda}{a}$
- Angular fringe width of central maximum $= \frac{2\lambda}{a}$.
- Angular fringe width of secondary maxima or minima $= \frac{\lambda}{a}$

Fresnel distance

It is the minimum distance a beam of light has to travel before its deviation from straight line path becomes significant.

Fresnel distance, $Z_F = \frac{a^2}{\lambda}$

Resolving Power

It is the ability of an optical instrument to produce distinctly separate images of two close objects *i.e.* it is the ability of the instrument to resolve or to see as separate, the images of two close objects.

Limit of resolution

The minimum distance between two objects which can just be seen as separate by the optical instrument is known as the limit of resolution of the instrument. Smaller the limit of resolution of the optical instrument, greater is its resolving power and vice-versa.

Rayleigh's criterion of limiting resolution

According to Rayleigh, two nearby images are said to be resolved if the position of the central maximum of one coincides with the first secondary minimum of the other and vice versa.

Resolving power of a microscope

It is defined as the reciprocal of the minimum distance d between two point objects, which can just be seen through the microscope as separate.

$$\text{Resolving power} = \frac{1}{d} = \frac{2\mu\sin\theta}{\lambda}$$

where μ is refractive index of the medium between object and objective lens, θ is half the angle of cone of light from the point object, d represents limit of resolution of microscope and $\mu\sin\theta$ is known as the numerical aperture.

Resolving power of a telescope

It is defined as reciprocal of the smallest angular separation ($d\theta$) between two distant objects, whose images are just seen in the telescope as separate.

$$\text{Resolving power} = \frac{1}{d\theta} = \frac{D}{1.22\,\lambda}$$

where D is diameter or aperture of the objective lens of the telescope, $d\theta$ represents limit of resolution of telescope.

Polarisation of Light

The phenomenon of restricting the vibrations of light (electric vector) in a particular direction, perpendicular to direction of wave motion is known as polarisation of light. The plane in which vibrations of polarised light are confined is known as plane of vibration. A plane which is perpendicular to the plane of vibration is known as plane of polarisation.

Angle of Polarisation

The angle of incidence for which an ordinary light is completely polarised in the plane of incidence when it gets reflected from a transparent medium.

Laws of Malus

According to law of Malus, when a beam of completely plane polarised light is incident on an analyser, the resultant intensity of light (I) transmitted from the analyser varies directly as the square of the cosine of the angle (θ) between plane of trasmission of analyser and polariser *i.e.* $I \propto \cos^2\theta$

Brewster's law

According to Brewster's law, when unpolarised light is incident at polarising angle (i_p) on an interface separating a rarer medium from a denser medium of refractive index μ, such that

$$\mu = \tan i_p$$

then light reflected in the rarer medium is completely polarised. The reflected and refracted rays are perpendicular to each other.

Optical Rotation

It is the phenomenon of rotating the plane of polarisation of light about the direction of propagation of light, when passed through certain crystals or solutions.

Substances which rotate the plane of polarisation are known as optically active substances. These are of two types :

- **Dextro rotatory or right handed :** They rotate the plane of polarisation in clockwise direction.
- **Laevo rotatory or left handed :** They rotate the plane of polarisation in anticlockwise direction.

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EXAM DRILL

1. Two slits separated by a distance of 1 mm are illuminated with red light of wavelength 6.5×10^{-7} m. The interference fringes are observed on a screen placed 1 m from the slits. The distance between the third dark fringe and the fifth bright fringe is equal to

(a) 0.65 mm (b) 1.63 mm
(c) 3.25 mm (d) 4.88 mm

2. What is the minimum thickness of a thin film required for constructive interference in the reflected light from it ? Given, the refractive index of the film = 1.5, wavelength of the light incident on the film = 600 nm.

(a) 100 nm (b) 300 nm
(c) 50 nm (d) 200 nm

3. In a Young's double slit experiment using red and blue lights of wavelengths 600 nm and 480 nm respectively, the value of n for which the n^{th} red fringe coincides with $(n+1)^{th}$ blue fringe is

(a) 5 (b) 4
(c) 3 (d) 2

4. In Young's double slit experiment, one of the slits is wider than the other, so that the amplitude of the light from one slit is double that from the other slit. If I_m be the maximum intensity, the resultant intensity when they interfere at phase difference ϕ is given by

(a) $\frac{I_m}{3}\left(1+2\cos^2\frac{\phi}{2}\right)$ (b) $\frac{I_m}{5}\left(1+4\cos^2\frac{\phi}{2}\right)$

(c) $\frac{I_m}{9}\left(1+8\cos^2\frac{\phi}{2}\right)$ (d) $\frac{I_m}{9}\left(8+\cos^2\frac{\phi}{2}\right)$

5. In an interference experiment using waves of same amplitude, path difference between the waves at a point on the screen is $\lambda/4$. The ratio of intensity at this point to that at the central bright fringe is

(a) 1 (b) 0.5
(c) 1.5 (d) 2.0

6. Light of wavelength 2×10^{-3} m falls on a slit of width 4×10^{-3} m. The angular dispersion of the central maximum will be

(a) 30° (b) 60°
(c) 90° (d) 180°

7. The maximum number of possible interference maxima for slit separation equal to twice the wavelength in Young's double-slit experiment is

(a) infinite (b) five
(c) three (d) zero

8. A single slit is located effectively at infinity in front of a lens of focal length 1 m, and it is illuminated normally with light of wavelength 600 nm. The first minimum on either side of central maximum are separated by 4 mm. Width of the slit is

(a) 0.1 mm (b) 0.2 mm
(c) 0.3 mm (d) 0.4 mm

9. Angle between the plane of vibration and plane of polarization is

(a) 30° (b) 90°
(c) 60° (d) 70°

10. White light is incident on a glass plate of thickness 5000 Å and refractive index 1.5. The wavelength in the visible region (4000 Å – 7000 Å) that is strongly reflected by the plate is

(a) 4290 Å (b) 8000 Å
(c) 4000 Å (d) 5000 Å

11. A thin mica sheet of thickness 2×10^{-6} m and refractive index ($\mu = 1.5$) is introduced in the path of the light from upper slit. The wavelength of the wave used is 5000 Å. The central bright maximum will shift

(a) 2 fringes upward (b) 2 fringes downward
(c) 10 fringes upward (d) none of these

12. A light wave is incident normally over a single slit of width 24×10^{-5} cm. The angular position of second dark fringe from the central maxima is 30°. What is the wavelength of light?

(a) 6000 Å (b) 5000 Å
(c) 3000 Å (d) 1500 Å

13. A plane wave of wavelength 6250 Å is incident normally on a slit of width 2×10^{-2} cm. The width of the principal maximum on a screen distant 50 cm will be

(a) 312.5×10^{-3} cm (b) 312.5×10^{-4} cm
(c) 312 cm (d) 312.5×10^{-5} cm

14. Two waves of same frequency and same amplitude from two monochromatic sources are allowed to superpose at a certain point. If in one case the phase difference is 0° and in other case is $\pi/2$, the ratio of the intensities in the two cases will be

(a) 1 : 1 (b) 2 : 1
(c) 4 : 1 (d) none of these

15. The intensity ratio of the maxima and minima in an interference pattern produced by two coherent sources of light is 9 : 1. The intensities of the used light sources are in ratio

(a) 3 : 1 (b) 4 : 1
(c) 9 : 1 (d) 10 : 1

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16. When a light of wavelength 4000 Å in vacuum travels through the same thickness in diamond and water separately, the difference in the number of waves is 200. Find the thickness, if refractive indices of diamond and water are $\frac{5}{2}$ and $\frac{4}{3}$ respectively.

(a) 0.685 mm (b) 0.0685 mm
(c) 68.5 mm (d) 6.85 mm

17. A beam of natural light falls on a system of 5 polaroids, which are arranged in succession such that the pass axis of each polaroid is turned through 60° with respect to the preceding one. The fraction of the incident light intensity that passes through the system is

(a) $\frac{1}{64}$ (b) $\frac{1}{32}$
(c) $\frac{1}{256}$ (d) $\frac{1}{512}$

18. In a single slit diffraction pattern, the distance between the first minimum on the left and the first minimum on the right is 5 mm. The screen on which the diffraction pattern is displayed is at a distance of 80 cm from the slit. The wavelength is 6000 Å. The slit width (in mm) is about

(a) 0.576 (b) 0.348
(c) 0.192 (d) 0.096

19. In Young's double slit experiment, the 10^{th} maximum of wavelength λ_1 is at a distance of y_1 from the central maximum. When the wavelength of the source is changed to λ_2, 5^{th} maximum is at a distance of y_2 from its central maximum. The ratio $\left(\frac{y_1}{y_2}\right)$ is

(a) $\frac{2\lambda_1}{\lambda_2}$ (b) $\frac{2\lambda_2}{\lambda_1}$
(c) $\frac{\lambda_1}{2\lambda_2}$ (d) $\frac{\lambda_2}{2\lambda_1}$

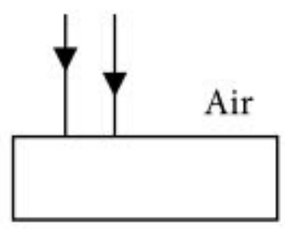
20. In Young's double slit experiment, first slit has width four times the width of the second slit. The ratio of the maximum intensity to the minimum intensity in the interference fringe system is

(a) 2 : 1 (b) 4 : 1
(c) 9 : 1 (d) 8 : 1

21. Angular width of central maximum in the Fraunhofer's diffraction pattern is measured. Slit is illuminated by the light of wavelength 6000 Å. If slit is illuminated by light of another wavelength, angular width decreases by 30%. Wavelength of light used is

(a) 3500 Å (b) 4200 Å
(c) 4700 Å (d) 6000 Å

22. A parallel beam of light of intensity I is incident on a glass plate. 25% of light is reflected in any reflection by upper surface and 50% of light is reflected by any reflection from lower surface. Rest is refracted.



The ratio of maximum to minimum intensity in interference region of reflected rays is

(a) $\left(\frac{\frac{1}{2}-\sqrt{\frac{3}{8}}}{\frac{1}{2}+\sqrt{\frac{3}{8}}}\right)^2$ (b) $\left(\frac{\frac{1}{2}+\sqrt{\frac{3}{8}}}{\frac{1}{2}-\sqrt{\frac{3}{8}}}\right)^2$

(c) $\left(\frac{1-\frac{3}{\sqrt{8}}}{1+\frac{3}{\sqrt{8}}}\right)^2$ (d) $\left(\frac{1+\frac{3}{\sqrt{8}}}{1-\frac{3}{\sqrt{8}}}\right)^2$

23. An unpolarized light beam is incident on a surface at an angle of incidence equal to Brewster's angle. Then,

(a) the reflected and the refracted beams are both partially polarized.
(b) the reflected beam is partially polarized and the refracted beam is completely polarized and are at right angles to each other.
(c) the reflected beam is completely polarized and the refracted beam is partially polarized and are at right angles to each other.
(d) both the reflected and the refracted beams are completely polarized and are at right angles to each other.

24. If the ratio of maximum and minimum intensities of an interference pattern is 36 : 1, then the ratio of amplitudes of the two interfering waves will be

(a) 3 : 7 (b) 7 : 4
(c) 4 : 7 (d) 7 : 5

25. What is the minimum thickness of a soap film needed for constructive interference in reflected light, if the light incident on the film is of 750 nm? Assume that the index for the film is $\mu = 1.33$.

(a) 282 nm (b) 70.5 nm
(c) 141 nm (d) 387 nm

26. An astronaut is looking down on Earth's surface from a space shuttle at an altitude of 400 km. Assuming that the astronaut's pupil diameter is 5 mm and the wavelength of visible light is 500 nm, the astronaut will be able to resolve linear objects of the size of about

(a) 0.5 m (b) 5 m
(c) 50 m (d) 500 m

27. When one of the slits of Young's experiment is covered with a transparent sheet of thickness 4.8 mm, the central fringe shifts to a position originally

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occupied by the 30th bright fringe. What should be the thickness of the sheet if the central fringe has to shift to the position occupied by 20th bright fringe?

(a) 3.8 mm (b) 1.6 mm
(c) 7.6 mm (d) 3.2 mm

28. Two identical coherent sources placed on a diameter of a circle of radius R at separation x ($< < R$) symmetrically about the centre of the circle. The sources emit identical wavelength λ each. The number of points on the circle with maximum intensity is ($x = 5\lambda$)

(a) 24 (b) 20
(c) 22 (d) 26

29. In YDSE, two slits are made 5 mm apart and the screen is placed 2 m away. What is the fringe separation when light of wavelength 500 nm is used?

(a) 0.002 mm (b) 0.02 mm
(c) 0.2 mm (d) 2 mm

30. The path difference between two interfering waves at a point on the screen is $\lambda/8$. The ratio of the intensity at this point and that at the central fringe will be

(a) 0.853 (b) 8.53
(c) 85.3 (d) 853

31. A beam of light of wavelength 600 nm from a distant source falls on a single slit 1.00 mm wide and the resulting diffraction pattern is observed on a screen 2 m away. The distance between the first dark fringes on either side of the central bright fringe is

(a) 1.2 cm (b) 1.2 mm
(c) 2.4 cm (d) 2.4 mm

32. A beam of unpolarised light having flux 10^{-3} watt falls normally on a polarizer of cross sectional area 3×10^{-4} m^2. The polarizer rotates with an angular frequency of 31.4 rad s^{-1}. The energy of light passing through the polarizer per revolution will be

(a) 10^{-4} joule (b) 10^{-3} joule
(c) 10^{-2} joule (d) 10^{-1} joule

33. Laser light of wavelength 630 nm incident on a pair of slits produces an interference pattern in which the bright fringes are separated by 8.1 mm. A second light produces an interference pattern in which the fringes are separated by 7.2 mm. The wavelength of the second light is

(a) 420 nm (b) 560 nm
(c) 810 nm (d) 980 nm

34. In Young's double slit experiment, light of wavelength 6000 Å is used to get an interference pattern on a screen. The fringe width changes by 1.5 mm, when the screen is brought towards the double slit by 50 cm. The distance between the two slits is

(a) 0.2 mm (b) 0.4 mm
(c) 0.6 mm (d) 0.8 mm

35. Out of the following, which can be used as coherent sources required to produce interference pattern of light ?

(a) Two identical and independent sodium lamps
(b) One yellow light and one green light source
(c) Two light sources with unequal amplitude
(d) None of these

36. The polarising angle for a medium is 60°. The critical angle for the medium is

(a) $\sin^{-1}\left(\frac{1}{2}\right)$ (b) $\cos^{-1}\left(\frac{1}{\sqrt{3}}\right)$

(c) $\cos^{-1}\left(\frac{1}{2}\right)$ (d) $\sin^{-1}\left(\frac{1}{\sqrt{3}}\right)$

37. Which of the following waves cannot be polarised ?

(a) Radiowaves (b) Infrared waves
(c) Ultrasonic waves (d) Microwaves

38. In the Young's double slit experiment using a monochromatic light of wavelength λ, the path difference (in terms of an integer n) corresponding to any point having half the peak intensity is

(a) $(2n+1)\frac{\lambda}{2}$ (b) $(2n+1)\frac{\lambda}{4}$

(c) $(2n+1)\frac{\lambda}{8}$ (d) $(2n+1)\frac{\lambda}{16}$

39. Diffraction pattern from a single slit of width 0.25 mm is observed with light of wavelength 5890 Å. Angular separation between first order minimum and third order maximum, falling on the same side, is

(a) 5.89×10^{-3} rad (b) 5.89×10^{-7} rad
(c) 5.89×10^{-10} rad (d) 5.89×10^{-4} rad

40. A beam of unpolarised light is incident on two polaroids crossed to each other. When one of the polaroid is rotated through an angle, then 25% of the incident unpolarised light is transmitted by the polaroids. Then the angle through which polaroid is rotated, is

(a) 25° (b) 45°
(c) 0° (d) 90°

41. In a Young's double-slit experiment the slit separation is 0.5 mm and the screen is 0.5 m from the slit. For a monochromatic light of wavelength 500 nm the distance of third maxima from the second minima on the other side is

(a) 2.75 mm (b) 2.5 mm
(c) 22.5 mm (d) 2.25 mm

42. In Young's double slit experiment, the distance between the two slits is 0.1 mm and wavelength of light used is 4×10^{-7} m. If the width of fringe on screen is 4 mm, the distance between screen and slits is

(a) 0.1 mm (b) 1 cm
(c) 0.1 cm (d) 1 m

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43. Light from a source emitting two wavelengths λ_1 and λ_2 is allowed to fall on Young's double-slit apparatus after filtering one of the wavelengths. The position of interference maxima is noted. When the filter is removed both the wavelengths are incident and it is found that maximum intensity is produced where the fourth maxima occurred previously. If the other wavelength is filtered, at the same location the third maxima is found. Find the ratio of wavelengths.

(a) $\frac{2}{3}$ (b) $\frac{3}{5}$

(c) $\frac{3}{4}$ (d) $\frac{4}{5}$

44. In Young's double slit experiment, intensity at a point is $\left(\frac{1}{4}\right)$ of the maximum intensity. Angular position of this point is

(a) $\sin^{-1}\left(\frac{\lambda}{d}\right)$ (b) $\sin^{-1}\left(\frac{\lambda}{2d}\right)$

(c) $\sin^{-1}\left(\frac{\lambda}{3d}\right)$ (d) $\sin^{-1}\left(\frac{\lambda}{4d}\right)$

45. In Young's double slit experimental setup, if the wavelength alone is doubled, the band width β becomes

(a) $\frac{\beta}{2}$ (b) 2β

(c) 4β (d) β

DAY 24 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ

Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____

(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (b) : Here, $d = 1\text{ mm} = 10^{-3}\text{ m}$, $\lambda = 6.5 \times 10^{-7}\text{ m}$
$D = 1\text{ m}$

$$x_5 = n\lambda\frac{D}{d} = 5\times6.5\times10^{-7}\times\frac{1}{10^{-3}} = 32.5\times10^{-4}\text{ m}$$

$$x_3 = (2n-1)\frac{\lambda}{2}\frac{D}{d} = \frac{(2\times3-1)\times6.5\times10^{-7}\times1}{2\times10^{-3}}$$

$$= 16.25\times10^{-4}\text{ m}$$

$$x_5 - x_3 = (32.5 - 16.25)\times10^{-4}\text{ m}$$

$$= 16.25\times10^{-4}\text{ m} = 1.63\text{ mm}$$

2. (a) : Condition for constructive interference is

$$2\mu t = (2n+1)\frac{\lambda}{2}$$

where, $n = 0, 1, 2, 3, \ldots$
For minimum thickness, $n = 0$

$$2\mu t = \frac{\lambda}{2} \Rightarrow t = \frac{\lambda}{4\mu} = \frac{600\times10^{-9}}{4\times1.5} = 100\text{ nm}$$

3. (b) : Let n^{th} red coincides with m^{th} blue, then

$$\frac{n\lambda_R D}{d} = \frac{m\lambda_B D}{d}$$

$$\therefore \quad \frac{n}{m} = \frac{\lambda_B}{\lambda_R} = \frac{480}{600} = \frac{4}{5}$$

i.e, 4th red coincides with 5th blue. Next 8th red will coincide with 10th blue and so on. Thus,

$n = 4$ and $m = n + 1 = 5$

4. (c) : Here, $A_2 = 2A_1$

$\because$ Intensity $\propto$ (Amplitude)^2

$$\therefore \quad \frac{I_2}{I_1} = \left(\frac{A_2}{A_1}\right)^2 = \left(\frac{2A_1}{A_1}\right)^2 = 4$$

$$I_2 = 4I_1$$

Maximum intensity,

$$I_m = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2$$

$$= \left(\sqrt{I_1} + \sqrt{4I_1}\right)^2 = \left(3\sqrt{I_1}\right)^2 = 9I_1$$

or $\quad I_1 = \dfrac{I_m}{9}$ ...(i)

Resultant intensity, $I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$

$$= I_1 + 4I_1 + 2\sqrt{I_1(4I_1)}\cos\phi$$

$$= 5I_1 + 4I_1\cos\phi = I_1 + 4I_1 + 4I_1\cos\phi$$

$$= I_1 + 4I_1(1 + \cos\phi)$$

$$= I_1 + 8I_1\cos^2\frac{\phi}{2} \qquad \left(\because \quad 1 + \cos\phi = 2\cos^2\frac{\phi}{2}\right)$$

$$= I_1\left(1 + 8\cos^2\frac{\phi}{2}\right)$$

Putting the value of I_1 from eqn. (i), we get

$$I = \frac{I_m}{9}\left(1 + 8\cos^2\frac{\phi}{2}\right)$$

5. (b) : From $I_R = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$,

Here, $\phi = \dfrac{2\pi}{\lambda}\times\dfrac{\lambda}{4} = \dfrac{\pi}{2}$

$$\therefore \quad I_R = I + I + 2I\cos\frac{\pi}{2} = 2I$$

At the central bright fringe, $I_R' = 4I$

$$\therefore \quad \frac{I_R}{I_R'} = \frac{2I}{4I} = 0.5$$

6. (b) : Angular dispersion of central maximum = angular dispersion of 1st minimum (= 2θ)

From, $\sin\theta = \dfrac{\lambda}{d} = \dfrac{2\times10^{-3}}{4\times10^{-3}} = \dfrac{1}{2}$

or $\quad \theta = 30°$

$$\therefore \quad 2\theta = 2\times30° = 60°$$

7. (b) : As $d\sin\theta = n\lambda$ and $d = 2\lambda$, $2\sin\theta = n$ and as such maximum value of n = 2. Thus, interference maxima are formed when $n = 0$, $n = \pm1$, $n = \pm2$, *i.e*., maximum number of possible interference maxima is 5.

8. (c) : Here, $f = 1$ m, $\lambda = 600\text{ nm} = 6\times10^{-7}$ m,
$n = 1$, $2x = 4$ mm, $x = 2\text{ mm} = 2\times10^{-3}$ m, $a = ?$

As $\quad a = \dfrac{f\lambda}{x}$

$$a = \frac{1\times6\times10^{-7}}{2\times10^{-3}} = 3\times10^{-4}\text{ m} = 0.3\text{ mm}$$

9. (b) : Angle between the plane of vibration and plane of polarization is 90°.

10. (a) : Light of wavelength λ is strongly reflected if

$$2\mu t = (2n+1)\frac{\lambda}{2} \qquad \ldots (i)$$

If $\lambda = 4000$ Å, $n = 3.25$
If $\lambda = 7000$ Å, $n = 1.66$
Hence, within 4000 Å and 7000 Å the integer can take values 2 and 3. (from eq. (i)).
Putting $n = 3$, we get
$\lambda = 4290$ Å
Hence option is $\lambda = 4290$ Å

11. (a) : On introducing mica sheet,

$$\text{fringe shift} = \frac{\beta}{\lambda}(\mu - 1)t$$

where t is the thickness of sheet

$$\therefore \quad \text{Fringe shift} = \frac{\beta}{(5000\times10^{-10})}\times(1.5-1)\times(2\times10^{-6}) = 2\beta = 2\beta$$

So, central bright maximum will shift 2 fringes upward.

12. (a) : For n^{th} dark fringe in single slit, $a\sin\theta = n\lambda$
For second dark fringe, $a\sin\theta = 2\lambda$
So, $24\times10^{-5}\times10^{-2}\times\sin30° = 2\lambda$
$\therefore \quad \lambda = 6\times10^{-7}\text{ m} = 6000$ Å

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13. (a) : Here, $\lambda = 6250\ \text{Å} = 6250 \times 10^{-10}$ m
$a = 2 \times 10^{-2}$ cm $= 2 \times 10^{-4}$ m, $D = 50$ cm $= 0.5$ m

$$\text{Width of central maximum} = \frac{2\lambda D}{a}$$

$$= \frac{2 \times 6250 \times 10^{-10} \times 0.5}{2 \times 10^{-4}} = 3125 \times 10^{-6}\ \text{m}$$

$$= 312.5 \times 10^{-3}\ \text{cm}$$

14. (b) : From $I_R = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$

When $\phi = 0°, I_R = I + I + 2\sqrt{II}\cos 0° = 4I$

When $\phi = 90°$, $I'_R = I + I + 2\sqrt{II}\cos 90° = 2I$

$$\therefore \quad \frac{I_R}{I'_R} = \frac{4I}{2I} = 2:1$$

15. (b) : $\dfrac{I_{\max}}{I_{\min}} = \dfrac{(a+b)^2}{(a-b)^2}$

$$\frac{9}{1} = \frac{(a+b)^2}{(a-b)^2}$$

or $\dfrac{3}{1} = \dfrac{a+b}{a-b}$ or $3a - 3b = a + b$

or $2a = 4b$ or $a = 2b$

$$\therefore \quad \frac{I_1}{I_2} = \frac{a^2}{b^2} = \frac{4}{1}$$

16. (b) : Here, $\mu_{\text{diamond}} = \dfrac{5}{2}$, $\mu_{\text{water}} = \dfrac{4}{3}$

$\lambda_{\text{vacuum}} = 4000\ \text{Å} = 4000 \times 10^{-10}$ m

Refractive index of diamond

$$\mu_{\text{diamond}} = \frac{\text{Wavelength of light in vacuum}}{\text{Wavelength of light in diamond}} = \frac{\lambda_{\text{vacuum}}}{\lambda_{\text{diamond}}}$$

$$\lambda_{\text{diamond}} = \frac{4000\ \text{Å}}{(5/2)} = 1600\ \text{Å}$$

Refractive index of water

$$\mu_{\text{water}} = \frac{\text{Wavelength of light in vacuum}}{\text{Wavelength of light in water}} = \frac{\lambda_{\text{vacuum}}}{\lambda_{\text{water}}}$$

$$\lambda_{\text{water}} = \frac{4000\ \text{Å}}{(4/3)} = 3000\ \text{Å}$$

Number of waves in thickness t of diamond,

$$n_{\text{diamond}} = \frac{t}{\lambda_{\text{diamond}}}$$

Number of waves in same thickness t of water,

$$n_{\text{water}} = \frac{t}{\lambda_{\text{water}}}$$

According to question,

$$n_{\text{diamond}} - n_{\text{water}} = 200$$

$$\frac{t}{\lambda_{\text{diamond}}} - \frac{t}{\lambda_{\text{water}}} = 200$$

$$t\left(\frac{\lambda_{\text{water}} - \lambda_{\text{diamond}}}{\lambda_{\text{diamond}}\,\lambda_{\text{water}}}\right) = 200$$

$$t\left(\frac{3000\ \text{Å} - 1600\ \text{Å}}{(1600\ \text{Å})(3000\ \text{Å})}\right) = 200$$

On solving, we get

$t = 6.85 \times 10^{-5}$ m $= 0.0685$ mm

17. (d) : Let I_0 be the intensity of incident light.
Then the intensity of light from the 1st polaroid is

$$I_1 = \frac{I_0}{2}$$

Intensity of light from the 2nd polaroid is

$$I_2 = I_1\cos^2 60° = \frac{I_0}{2}\left(\frac{1}{2}\right)^2 = \frac{I_0}{8}$$

Intensity of light from the 3rd polaroid is

$$I_3 = I_2\cos^2 60° = \frac{I_0}{8}\left(\frac{1}{2}\right)^2 = \frac{I_0}{32}$$

Intensity of light from the 4th polaroid is

$$I_4 = I_3\cos^2 60° = \frac{I_0}{32}\left(\frac{1}{2}\right)^2 = \frac{I_0}{128}$$

Intensity of light from 5th polaroid is

$$I_5 = I_4\cos^2 60° = \frac{I_0}{128}\left(\frac{1}{2}\right)^2 = \frac{I_0}{512}$$

Therefore, the fraction of the incident light that passes through the system is

$$\frac{I_5}{I_0} = \frac{1}{512}$$

18. (c) : Distance between the first minimum on the left and the first minimum on the right is also the width of central maximum.

Width of central maximum, $W = \dfrac{2\lambda D}{a}$

where, λ = Wavelength of light

a = Width of the slit

D = Distance of the screen from the slit

$$\therefore \quad a = \frac{2\lambda D}{W}$$

Here, $\lambda = 6000\ \text{Å} = 6000 \times 10^{-10}$ m,

$D = 80$ cm $= 80 \times 10^{-2}$ m

$W = 5$ mm $= 5 \times 10^{-3}$ m

$$\therefore \quad a = \frac{2 \times 6000 \times 10^{-10}\,\text{m} \times 80 \times 10^{-2}\ \text{m}}{5 \times 10^{-3}\,\text{m}}$$

$$= 19.2 \times 10^{-5}\,\text{m} = 0.192 \times 10^{-3}\,\text{m} = 0.192\,\text{mm}$$

19. (a) : The distance of 10th maximum of wavelength λ_1 from the central maximum is

$$y_1 = 10\lambda_1\frac{D}{d}$$

where D is the distance of the slits from the screen and d is the distance between the slits.

The distance of 5th maximum of wavelength λ_2 from the central maximum is

$$y_2 = 5\lambda_2\frac{D}{d}$$

$$\therefore \quad \frac{y_1}{y_2} = \frac{2\lambda_1}{\lambda_2}$$

20. (c) : If W_1 and W_2 are widths of two slits, then

$$\frac{I_1}{I_2} = \frac{W_1}{W_2} = 4$$

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Also, $\frac{I_1}{I_2}=\frac{A_1^2}{A_2^2}$ $\therefore$ $\frac{A_1^2}{A_2^2}=4$ or $\frac{A_1}{A_2}=2$

$$\frac{I_{max}}{I_{min}}=\left(\frac{A_1+A_2}{A_1-A_2}\right)^2=\frac{\left(\frac{A_1}{A_2}+1\right)^2}{\left(\frac{A_1}{A_2}-1\right)^2}=\frac{(2+1)^2}{(2-1)^2}=\frac{9}{1}$$

21. (b) : In case of single slit diffraction experiment the angular width of central maximum is given by

$$\theta=\frac{2\lambda}{a}$$

where, a = width of the slit

λ = wavelength of the light

$\therefore$ $\frac{\theta'}{\theta}=\frac{\lambda'}{\lambda}$

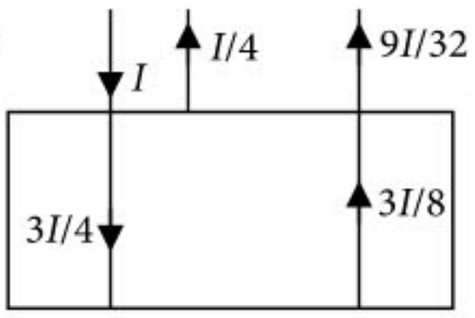
According to given problem

$$\theta'=\theta-\frac{30}{100}\theta=0.70\theta$$

$\therefore$ $\frac{\lambda'}{\lambda}=\frac{0.7\theta}{\theta}=0.7$

$\lambda'=0.7\lambda=0.7\times6000\ \text{Å}=4200\ \text{Å}$

22. (d) :



$I_1=\frac{I}{4}$ and $I_2=\frac{9I}{32}$

$\therefore$ $\frac{I_1}{I_2}=\frac{8}{9}$ or $\sqrt{\frac{I_1}{I_2}}=\frac{2\sqrt{2}}{3}$

$\therefore$ $\frac{I_{max}}{I_{min}}=\left(\frac{\sqrt{\frac{I_1}{I_2}}+1}{\sqrt{\frac{I_1}{I_2}}-1}\right)^2=\left(\frac{2\sqrt{2}+3}{2\sqrt{2}-3}\right)^2=\left(\frac{1+\frac{3}{\sqrt{8}}}{1-\frac{3}{\sqrt{8}}}\right)^2$

23. (c)

24. (d) : Let A_1 and A_2 be amplitudes of the two interfering waves. Then

$$\frac{I_{max}}{I_{min}}=\frac{(A_1+A_2)^2}{(A_1-A_2)^2}$$

But $\frac{I_{max}}{I_{min}}=\frac{36}{1}$ (given)

$\therefore$ $\frac{(A_1+A_2)^2}{(A_1-A_2)^2}=\frac{36}{1}$

$\frac{A_1+A_2}{A_1-A_2}=\frac{6}{1}$

$A_1+A_2=6(A_1-A_2)$

$A_1+A_2=6A_1-6A_2$

$5A_1=7A_2$ or $\frac{A_1}{A_2}=\frac{7}{5}$

25. (c) : Here, $2\mu t=\frac{\lambda}{2}$

$\therefore$ $t_{min}=\frac{\lambda}{4\mu}=141\ \text{nm}$

26. (c) : As $d\theta=\frac{x}{d}=\frac{1.22\lambda}{D}$, $\therefore$ $x=\frac{1.22\lambda d}{D}$

$$=\frac{1.22(500\times10^{-9}\ \text{m})(400\times10^{3}\ \text{m})}{(5\times10^{-3}\ \text{m})}=48.8\ \text{m}\approx50\ \text{m}$$

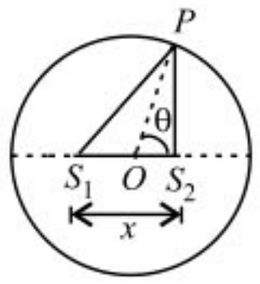
27. (d) : $\Delta x=\frac{D(\mu-1)t}{d}$. Also $\Delta x=\frac{nD\lambda}{d}$.

$\therefore$ $\frac{D(\mu-1)t}{d}=\frac{nD\lambda}{d}$ or $(\mu-1)t=n\lambda$

or $\frac{t_1}{t_2}=\frac{n_1}{n_2}\Rightarrow t_2=\frac{n_2t_1}{n_1}$

or $t_2=\frac{20\times4.8}{30}=3.2$ mm.

28. (b) : As is clear from figure, path difference between the light waves reaching P from S_1 and S_2 is



$$\Delta x=2\left(\frac{x}{2}\cos\theta\right)=x\cos\theta$$

For intensity to be maximum at P,

path difference $\Delta x=n\lambda$, where $n=0, 1, 2, ...$

$$x\cos\theta=n\lambda \quad \text{or} \quad \cos\theta=\frac{n\lambda}{x}$$

As $\cos\theta$ cannot be greater than one, therefore,

$$\frac{n\lambda}{x}\not>1 \quad \text{or} \quad n\not>\frac{x}{\lambda}$$

As $x=5\lambda$, therefore, $n\not>\frac{5\lambda}{\lambda}$

i.e., $n\not>5$ or $n=1, 2, 3, 4, 5.$

Therefore, in all the four quadrants, there can be 20 maxima.

29. (c) : Here, $d=5\ \text{mm}=5\times10^{-3}$ m, $D=2$ m

$\lambda=500\ \text{nm}=5\times10^{-7}$ m

$$\beta=\frac{\lambda D}{d}=\frac{5\times10^{-7}\times2}{5\times10^{-3}}=2\times10^{-4}\ \text{m}=0.2\ \text{mm}$$

30. (a) : As $R^2=a^2+b^2+2ab\cos\phi$

and path difference of $\lambda/8$ is equivalent to phase difference of

$$\phi=\frac{2\pi}{8}=\frac{\pi}{4}$$

$\therefore$ $I_R=I+I+2\sqrt{II}\cos\frac{\pi}{4}=2I\left(1+\frac{1}{\sqrt{2}}\right)=3.414I$

$I_{max}=4I$

$\therefore$ $\frac{I_R}{I_{max}}=\frac{3.414I}{4I}=0.853$

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31. (d) : $\lambda = 600 \text{ nm} = 6 \times 10^{-7} \text{ m}$
$a = 1 \text{ mm} = 10^{-3} \text{ m}$, $D = 2 \text{ m}$
Distance between the first dark fringes on either side of central bright fringe = width of central maximum

$$= \frac{2\lambda D}{a} = \frac{2 \times 6 \times 10^{-7} \times 2}{10^{-3}}$$

$$= 24 \times 10^{-4} \text{ m} = 2.4 \text{ mm}$$

32. (a) : Here, $\omega = 31.4 \text{ rad s}^{-1}$
$\therefore$ Time period of revolution,

$$T = \frac{2\pi}{\omega} = \frac{2 \times 3.14}{31.4} = 0.2 \text{ s}$$

Energy transmitted/revolution

$$= (IA)T = \left(\frac{I_0}{2} A\right) T$$

$$= \frac{\phi_0 T}{2} = \frac{10^{-3} \times 0.2}{2} = 10^{-4} \text{ joule}$$

33. (b) : Here $\lambda_1 = 630 \text{ nm}$, $\beta_1 = 8.1 \text{ mm}$, $\beta_2 = 7.2 \text{ mm}$

Fringe width, $\beta = \frac{D\lambda}{d}$

For constant D and d, $\beta \propto \lambda$

$$\therefore \quad \frac{\beta_2}{\beta_1} = \frac{\lambda_2}{\lambda_1}$$

$$\therefore \quad \lambda_2 = \frac{\beta_2}{\beta_1} \times \lambda_1 = \frac{7.2 \text{ mm}}{8.1 \text{ mm}} \times 630 \text{ nm} = 560 \text{ nm}.$$

34. (a) : Fringe width, $\beta = \frac{D\lambda}{d}$

As λ and d are constant, so the change in fringe width is given by

$$\Delta\beta = \frac{\lambda \Delta D}{d}$$

$\therefore$ Distance between the two slits,

$$d = \frac{\lambda \Delta D}{\Delta\beta} = \frac{6000 \times 10^{-10} \times 50 \times 10^{-2}}{1.5 \times 10^{-3}}$$

$$= 0.2 \times 10^{-3} \text{ m} = 0.2 \text{ mm}.$$

35. (d)

36. (d) : Here, $i_p = 60°$
Refractive index of the medium,

$$\mu = \tan i_p = \tan 60° = \sqrt{3}$$

Now, critical angle of the medium, i_c

$$= \sin^{-1}\left(\frac{1}{\mu}\right) = \sin^{-1}\left(\frac{1}{\sqrt{3}}\right)$$

37. (c) : Ultrasonic waves are longitudinal in nature, so they cannot be polarised.

38. (b) : As $I = I_{max} \cos^2\left(\frac{\phi}{2}\right)$

Here, $I = \frac{I_{max}}{2}$

$$\therefore \quad \frac{I_{max}}{2} = I_{max} \cos^2\left(\frac{\phi}{2}\right) \quad \Rightarrow \quad \frac{1}{2} = \cos^2\frac{\phi}{2}$$

$$\Rightarrow \quad \cos\phi = 0 \quad \Rightarrow \quad \phi = \frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2}, \ldots$$

or $\quad \phi = (2n+1)\frac{\pi}{2}$ where $n = 0, 1, 2, \ldots$

Since phase difference = $\frac{2\pi}{\lambda}$ × Path difference

$\therefore$ Path difference = $\frac{\lambda}{2\pi}$ × Phase difference

$$= \frac{\lambda}{2\pi} \times (2n+1)\frac{\pi}{2} = (2n+1)\frac{\lambda}{4}$$

39. (a) : In single slit diffraction pattern, positions of secondary maxima and minima are given by,

$\theta_{max} = \pm(2n+1)\frac{\lambda}{2d}$ and $\theta_{min} = \pm n\frac{\lambda}{d}$, respectively.

$$\therefore \quad \theta_{1\,min} = \frac{\lambda}{d} \text{ and } \theta_{3\,max} = \frac{7\lambda}{2d}$$

Angular separation = $\theta_{3\,max} - \theta_{1\,min} = \frac{7\lambda}{2d} - \frac{\lambda}{d}$

$$= \frac{5\lambda}{2d} = \frac{5}{2} \times \frac{5890 \times 10^{-10}}{0.25 \times 10^{-3}} = 5.89 \times 10^{-3} \text{ rad.}$$

40. (b) : Let I_0 be intensity of incident light, then the intensity of light emerging from the first polaroid,

$$I_1 = \frac{I_0}{2}$$

Initially, the two polaroids are crossed to each other *i.e.* $\theta_i = 90°$
Let the polaroid be rotated by angle θ, then the angle between polarising directions is $90° - \theta$
Now, intensity of light emerging from the second polaroid,

$$I_2 = I_1 \cos^2(90° - \theta) = \frac{I_0}{2} \cos^2(90° - \theta)$$

Also, $I_2 = 25\%$ of $I_0 = \frac{I_0}{4}$

$$\therefore \quad \frac{I_0}{4} = \frac{I_0}{2} \cos^2(90° - \theta)$$

$$\Rightarrow \quad \cos^2(90° - \theta) = \frac{1}{2}$$

or $\quad \cos(90° - \theta) = \frac{1}{\sqrt{2}} = \cos 45°$

or $\quad \theta = 90° - 45° = 45°$

41. (d) : Here, $d = 0.5 \text{ mm} = 0.5 \times 10^{-3} \text{ m}$
$D = 0.5 \text{ m}$, $\lambda = 500 \text{ nm} = 500 \times 10^{-9} \text{ m}$
The distance of third maxima from the second minima on the other side is

$$= \frac{9}{2}\beta \text{ (where } \beta \text{ is the fringe width)}$$

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$$= \frac{9}{2}\frac{\lambda D}{d} = \frac{9 \times 500 \times 10^{-9} \times 0.5}{2 \times 0.5 \times 10^{-3}}$$

$$= 2.25 \times 10^{-3}\ \text{m} = 2.25\ \text{mm}$$

42. (d) : Fringe width, $\beta = \frac{\lambda D}{d}$, $D = \frac{\beta d}{\lambda}$

$$D = \frac{4 \times 10^{-3} \times 0.1 \times 10^{-3}}{4 \times 10^{-7}} = 1\ \text{m}$$

43. (c) : The maxima is obtained whenever

$$x_{cm} = \frac{n\lambda D}{d}.$$

For first wavelength,

$$(x_4)_{\lambda_1} = \frac{4\lambda_1 D}{d}$$

For second wavelength, $(x_x)_{\lambda_2} = \frac{3\lambda_2 D}{d}$

$\because \quad (x_4)_{\lambda_1} = (x_3)_{\lambda_2}$

$$\therefore \quad \frac{4\lambda_1 D}{d} = \frac{3\lambda_2 D}{d} \Rightarrow \frac{\lambda_1}{\lambda_2} = \frac{3}{4}$$

44. (c) : In Young's double slit experiment, intensity at any point P is given by

$$I = I_{max} \cos^2\left(\frac{\phi}{2}\right)$$

where ϕ is the phase difference

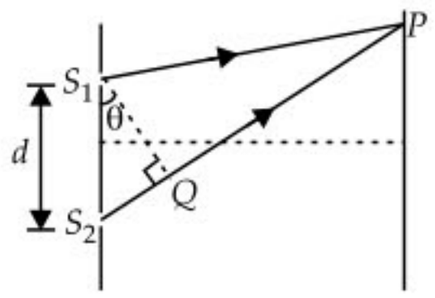
According to question, $I = \frac{I_{max}}{4}$

$$\frac{I_{max}}{4} = I_{max}\cos^2\left(\frac{\phi}{2}\right) \quad \text{or} \quad \cos\frac{\phi}{2} = \frac{1}{2} = \cos\frac{\pi}{3}$$

$$\therefore \quad \phi = \frac{2\pi}{3}$$

If Δx is the path difference between two waves, then

$$\frac{\phi}{2\pi} = \frac{\Delta x}{\lambda}$$



or $\Delta x = \frac{\lambda}{2\pi}\phi = \frac{\lambda}{2\pi} \times \frac{2\pi}{3} = \frac{\lambda}{3}$

Phase difference, $\Delta x = d\sin\theta$

or $d\sin\theta = \frac{\lambda}{3}$ or $\theta = \sin^{-1}\left(\frac{\lambda}{3d}\right)$

45. (b) : Fringe width, $\beta = \frac{\lambda D}{d}$ ...(i)

where λ is the wavelength of the light, D is the distance between the slits and the screen and d is the distance between two slits

When λ alone is doubled, while the other parameters remain unchanged, then fringe width becomes

$$\beta' = \frac{(2\lambda)D}{d} = 2\beta \qquad \text{(Using (i))}$$

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Unit Test 4

- Electromagnetic Induction
- Alternating Currents • Electromagnetic Waves
- Ray Optics and Optical Instruments
- Wave Optics

Unit test is complementary part of the learning process. It gives you a total insight whether the learning outcomes have been achieved or not. After doing daywise preparation, attempt these questions in exam like environment. This will assist you in finding particular area of weakness to work upon. An OMR sheet is given at the end to fill the correct answers.

All the Best!

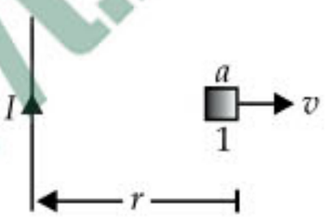
Max. Marks : 180 **Time : 45 min.**

1. A 16 μF capacitor is charged to a 20 V potential. The battery is then disconnected and a pure 40 mH coil is connected across the capacitor so that LC oscillations are set up. The maximum current in the coil is
(a) 0.2 A (b) 40 mA
(c) 2 A (d) 0.4 A

2. In Young's double slit expt., the distance between two sources is 0.1 mm. The distance of the screen from the source is 20 cm. Wavelength of light used is 5460 Å. The angular position of the first dark fringe is
(a) 0.08° (b) 0.16°
(c) 0.20° (d) 0.32°

3. A concave lens of focal length 20 cm placed in contact with a plane mirror acts as a
(a) convex mirror of focal length 10 cm
(b) concave mirror of focal length 40 cm
(c) concave mirror of focal length 60 cm
(d) concave mirror of focal length 10 cm

4. A square loop of side a placed in the same plane as a long straight wire carrying a current I. The centre of the loop is at a distance r from the wire, where $r >> a$.



The loop is moved away from the wire with a constant velocity v. The induced emf in the loop is
(a) $\frac{\mu_0 Iav}{2\pi r}$ (b) $\frac{\mu_0 Ia^3 v}{2\pi r^3}$
(c) $\frac{\mu_0 Iv}{2\pi}$ (d) $\frac{\mu_0 Ia^2 v}{2\pi r^2}$

5. The focal length of a biconvex lens of refractive index 1.5 is 0.06 m. Radius of curvatures are in the ratio 1 : 2. Then radii of curvatures of two lens surface are
(a) 0.045 m, 0.09 m (b) 0.09 m, 0.18 m
(c) 0.04 m, 0.08 m (d) 0.06 m, 0.12 m

6. The size of the image of an object, which is at infinity, as formed by a convex lens of focal length 30 cm is 2 cm. If a concave lens of focal length 20 cm is placed between the convex lens and the image at a distance of 26 cm from the convex lens, then the new size of the image is
(a) 1.25 cm (b) 2.5 cm
(c) 1.05 cm (d) 2 cm

7. Two point white dots are 1 mm apart on a black paper. They are viewed by an eye of pupil of diameter 3 mm. Approximately, what is the maximum distance at which these dots can be resolved by the eye? (Take wavelength of light = 500 nm)
(a) 5 m (b) 1 m
(c) 6 m (d) 3 m

8. A cubical room is formed with six plane mirrors. An insect moves along the diagonal of the floor with uniform speed. The velocities of its images in two adjacent walls are $20\sqrt{2}$ cm s^{-1}, then the velocity of the image formed by the roof is
(a) $10\sqrt{2}$ cm s^{-1} (b) 20 cm s^{-1}
(c) $20\sqrt{2}$ cm s^{-1} (d) 40 cm s^{-1}

9. Two coils have a mutual inductance 0.005 H. The current changes in the first coil according to equation $I = I_0 \sin\omega t$, where $I_0 = 10$ A and $\omega = 100\pi$ rad s^{-1}. The maximum value of emf in the second coil is (in V)
(a) 2π (b) 5π
(c) π (d) 4π

10. A convex lens is placed between object and a screen. The size of object is 3 cm and an image of height 9 cm is obtained on the screen. When the lens is displaced to a new position, what will be the size of image on the screen?
(a) 2 cm (b) 6 cm
(c) 4 cm (d) 1 cm

11. Resonance occurs in a series LCR circuit when the frequency of the applied emf is 1000 Hz. Then
(a) when υ = 900 Hz, the circuit behaves as a capacitative circuit.
(b) the impedance of the circuit is maximum at $\upsilon = 1000$ Hz.
(c) at resonance the voltage across L and voltage across C differ in phase by 180°.
(d) if the value of C is doubled resonance occurs at $\upsilon = 2000$ Hz.

12. In a series resonant LCR circuit, the voltage across R is 100 V and the value of $R = 1000\ \Omega$. The capacitance of the capacitor is 2×10^{-6} F, angular frequency of ac is 200 rad s^{-1}. Then the potential difference across the inductance coil is

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(a) 100 V (b) 40 V
(c) 250 V (d) 400 V

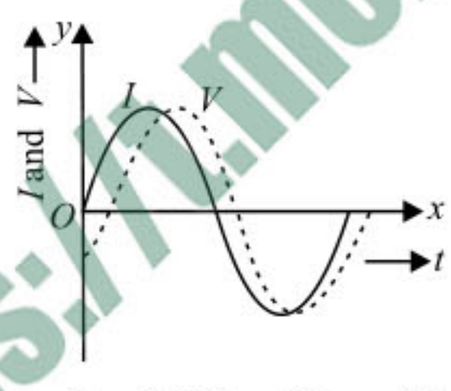
13. The magnifying power of a telescope is 9. When it is adjusted for parallel rays the distance between the objective and eyepiece is 20 cm. The focal length of lenses are
(a) 10 cm, 10 cm (b) 15 cm, 5 cm
(c) 18 cm, 2 cm (d) 11 cm, 9 cm

14. The radius of curvature of a thin plano-convex lens is 10 cm (of curved surface) and the refractive index is 1.5. If the plane surface is silvered, then the focal length will be
(a) 15 cm (b) 20 cm
(c) 5 cm (d) 10 cm

15. An ideal choke takes a current of 10 A when connected to an AC supply of 125 V and 50 Hz. A pure resistor under the same conditions takes a current of 12.5 A. If the two are connected to an AC supply of $100\sqrt{2}$ V and 40 Hz, then the current in series combination of above resistor and inductor is
(a) 10 A (b) 12.5 A
(c) 20 A (d) 25 A

16. The image of an electric bulb fixed in a wall is to be obtained on the wall opposite to it at a distance of 3 m. The maximum possible focal length of the convex lens is
(a) 3.25 m (b) 1.55 m
(c) 0.75 m (d) 0.28 m

17. When an ac source of voltage $V = V_0 \sin 100t$ is connected across a circuit, the phase difference between the voltage V and current I in the circuit is observed to be $\pi/4$, as shown in figure.



If the circuit consists possibly only of RC or RL or LC in series, find possible values of two elements.
(a) $R = 1\ \text{k}\Omega$, $C = 10\ \mu\text{F}$ (b) $R = 1\ \text{k}\Omega$, $C = 1\ \mu\text{F}$
(c) $R = 1\ \text{k}\Omega$, $L = 10\ \text{mH}$ (d) $R = 10\ \text{k}\Omega$, $L = 10\ \text{mH}$

18. A thin equiconvex lens has focal length 10 cm and refractive index 1.5. One of its faces is now silvered and for an object placed at a distance u in front of the lens, the image coincides with the object. The value of u is
(a) 10 cm (b) 5 cm
(c) 15 cm (d) 20 cm

19. The electric current in a circular coil of two turns produced a magnetic induction of 0.2 T at its centre. The coil is unwound and is rewound into a circular coil of four turns. The magnetic induction at the centre of the coil now is, in tesla (if same current flows in the coil)
(a) 0.2 (b) 0.4 (c) 0.6 (d) 0.8

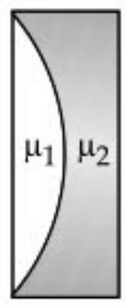
20. In a series LCR circuit the voltage across the resistance, capacitance and inductance is 10 V each. If the capacitance is short circuited, the voltage across the inductance will be
(a) 10 V (b) $10\sqrt{2}$ V
(c) $(10/\sqrt{2})$ V (d) 20 V

21. A plane electromagnetic wave of frequency 25 MHz travels in free space along the x-direction. At a particular point in space and time, $\vec{E} = 6.3\,\hat{j}$ V m^{-1} At this point B is equal to
(a) $8.33\times10^{-8}\,\hat{k}$ T (b) $18.9\times10^{-8}\,\hat{k}$ T
(c) $2.1\times10^{-8}\,\hat{k}$ T (d) $2.1\times10^{-8}\,\hat{i}$ T

22. Angle of a prism is A and its one surface is silvered. Light rays falling at an angle of incidence of $2A$ on first surface return back through the same path after suffering reflection at the second silvered surface. Refractive index of the material is
(a) $2\sin A$ (b) $2\cos A$
(c) $(1/2)\cos A$ (d) $\tan A$

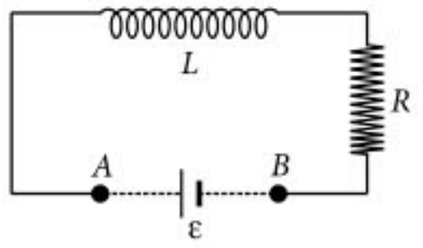
23. In Young's double slit experiment $\frac{d}{D} = 10^{-4}$ (d = distance between slits, D = distance of screen from the slits). At a point P on the screen the resulting intensity is equal to the intensity due to individual slit I_0. Then the distance of point P from the central maximum is (Take $\lambda = 6000$ Å)
(a) 2 mm (b) 1 mm
(c) 0.5 mm (d) 4 mm

24. A plano-convex lens fits exactly into a plano-concave lens. Their plane surfaces are parallel to each other. If the lenses are made of different materials of refractive indices μ_1 and μ_2 and R is the radius of curvature of the curved surfaces of the lenses, then the focal length of the combination is



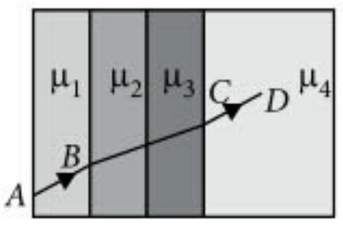
(a) $\frac{R}{(\mu_1-\mu_2)}$ (b) $\frac{2R}{(\mu_2-\mu_1)}$
(c) $\frac{R}{2(\mu_1-\mu_2)}$ (d) $\frac{R}{2-(\mu_1+\mu_2)}$

25. An inductor (L = 100 mH), a resistor (R = 100 Ω) and a battery (ε = 100 V) are initially connected in series as shown in figure.



After sometime, the battery is disconnected after short circuiting the points A and B. The current in the circuit 1 ms after the short circuit is
(a) e A (b) 0.1 A
(c) 1 A (d) $1/e$ A

26. A ray of light passes through four transparent media with refractive indices μ_1, μ_2, μ_3 and μ_4 as shown in the adjacent figure. The surfaces of all media are parallel. If the emergent ray CD is parallel to the incident ray AB, we must have



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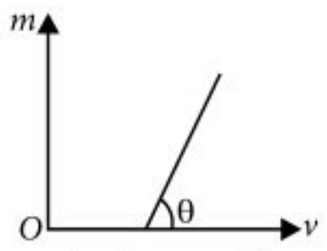
(a) $\mu_1 = \mu_3$ (b) $\mu_2 = \mu_4$
(c) $\mu_4 = \mu_1$ (d) $\mu_2 = \mu_3$

27. X-rays, gamma rays and microwaves travelling in vacuum have
(a) same wavelengths but different velocities
(b) same frequency but different velocities
(c) same velocity but different wavelengths
(d) same velocity and same frequency

28. Variation of magnification (m) produced by a thin convex lens versus distance of image from pole of the lens (v) is shown in the graph. Which of the following statements is not correct?



(a) Focal length of the lens is equal to intercept on v-axis.
(b) Focal length of the lens is equal to inverse of slope of the line.
(c) Magnitude of intercept on m-axis is equal to unity.
(d) Magnitude of intercept on v-axis is equal to unity.

29. What is the value of inductance L for which the current is maximum in a series LCR circuit with $C = 10\ \mu F$ and $\omega = 1000\ s^{-1}$?
(a) 100 mH (b) 1 mH
(c) 10 mH
(d) Cannot be calculated unless R is known

30. A ray of light is passing from air into glass. If the angle of incidence, with respect to the normal to the interface, is increased
(a) Total internal reflection will occur when the angle of incidence equals the critical angle.
(b) Total internal reflection will occur when the angle of incidence is less than the critical angle.
(c) Total internal reflection will occur when the angle of incidence is greater than the critical angle.
(d) Angle of refraction will increase but there will be no total internal reflection.

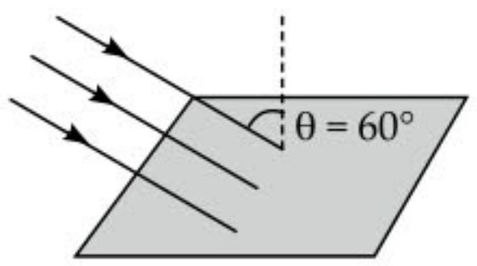
31. Two glass plates are touching at one end and separated by a thin wire at the other end. When a monochromatic parallel beam of wavelength 4200 Å incident normally on the glass plates is reflected, an interference pattern of 30 fringes is observed. If the wavelength of light used is taken 7000 Å instead of 4200 Å, the number of fringes observed will be
(a) 50 (b) 40
(c) 30 (d) 18

32. A transformer is having 2100 turns in primary coil and 4200 turns in secondary coil. An *ac* source of 120 V, 10 A is connected to its primary. The secondary voltage and current are
(a) 240 V, 5 A (b) 120 V, 10 A
(c) 240 V, 10 A (d) 120 V, 20 A

33. In single slit experiment, the width of the slit is reduced. Then, the linear width of the principal maxima
(a) increases but becomes less bright
(b) decreases but becomes more bright
(c) increases but becomes more bright
(d) decreases but becomes less bright

34. In a biprism experiment, by using light of wavelength 5000 Å, 5 mm wide fringes are obtained on a screen 1.0 m away from the coherent sources. The separation between the two coherent sources is
(a) 1.0 mm (b) 0.1 mm
(c) 0.05 mm (d) 0.01 mm

35. A square loop of wire of side 5 cm is lying on a horizontal table. An electromagnet above and to one side of the loop is turned on, causing a uniform magnetic field downwards at an angle of 60° to the vertical as shown in figure. The magnetic induction is 0.50 T. The average induced emf in the loop, if the field increases from zero to its final value in 0.2 s is



(a) 5.4×10^{-3} V
(b) 3.12×10^{-3} V
(c) 0
(d) 0.25×10^{-3} V

36. Light of wavelength λ is incident on a slit of width d. The resulting diffraction pattern is observed on a screen at a distance D. The linear width of the principal maximum is then equal to the width of the slit if D equals
(a) (d/λ) (b) $(2\lambda/d)$
(c) $(d^2/2\lambda)$ (d) $(2\lambda^2/d)$

37. A transparent cube of 15 cm edge contains a small air bubble. Its apparent depth when viewed through one face is 6 cm and when viewed through opposite face is 4 cm. The refractive index of material of cube is
(a) 2.0 (b) 1.5
(c) 1.6 (d) 2.5

38. In a Young's double slit experiment, $d = 0.5$ mm and $D = 100$ cm. It is found that 9^{th} bright fringe is at a distance of 7.5 mm from the second dark fringe of fringe pattern. The wavelength of light used is (in Å)
(a) $\frac{2500}{7}$ (b) 2500
(c) 5000 (d) $\frac{5000}{7}$

39. A thin lens ($\mu = 1.5$) of focal length + 10 cm is immersed in water ($\mu = 1.33$). The new focal length is
(a) 20 cm (b) 40 cm
(c) 48 cm (d) 12 cm

40. A small coin is resting on the bottom of a beaker filled with liquid. A ray of light from the coin travels upto the surface of the liquid and moves along its surface. How fast is the light travelling in the liquid?

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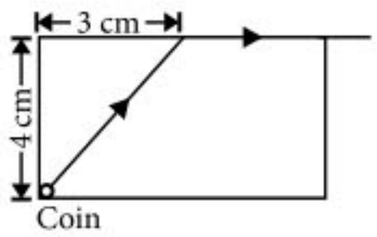
(a) 2.4×10^8 m s^{-1}
(b) 3.0×10^8 m s^{-1}
(c) 1.2×10^8 m s^{-1}
(d) 1.8×10^8 m s^{-1}

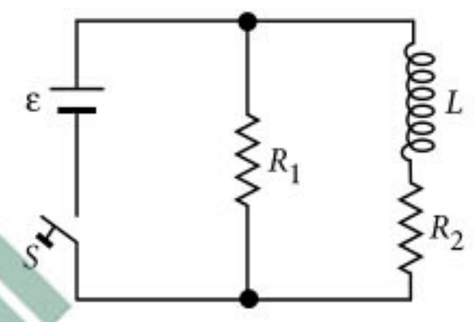


41. A thin prism P_1 with angle of the prism 4° made from glass of refractive index 1.54 is combined with another thin prism P_2 made from glass of refractive index 1.72 to produce dispersion without deviation. The angle of the prism P_2 is
(a) 5.33° (b) 4°
(c) 3° (d) 2.6°

42. A sinusoidal voltage of peak value 283 V and frequency 50 Hz is applied to a series *LCR* circuit in which $R = 3\ \Omega$, $L = 25.48$ mH, and $C = 796\ \mu$F. The impedance of the circuit is
(a) 4 Ω (b) 5 Ω
(c) 6 Ω (d) 7 Ω

43. The rms value of the electric field of the light coming from the sun is 720 N C^{-1}. The average total energy density of the electromagnetic wave is
(a) 3.33×10^{-3} J m^{-3} (b) 4.58×10^{-6} J m^{-3}
(c) 6.37×10^{-9} J m^{-3} (d) 81.35×10^{-12} J m^{-3}.

44. An inductor of inductance $L = 400$ mH and resistors of resistance $R_1 = 2\ \Omega$ and $R_2 = 2\ \Omega$ are connected to a battery of e.m.f. 12 V as shown in figure. The internal resistance of the battery is negligible. The switch S is closed at $t = 0$. The potential drop across L as a function of time is



(a) $\frac{12}{t}e^{-3t}$ V
(b) $t(1 - e^{-t/0.2})$ V
(c) $12\,e^{-5t}$ V
(d) $6\,e^{-5t}$ V

45. A resistor of 500 Ω, an inductance of 0.5 H are in series with an a.c. which is given by $V = 100\sqrt{2}\sin(1000t)$. The power factor of the combination is
(a) $\frac{1}{\sqrt{2}}$ (b) $\frac{1}{\sqrt{3}}$ (c) 0.5 (d) 0.6

UNIT TEST 4 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____
(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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Dual Nature of Radiation and Matter

Photons

According to Planck's quantum theory of radiation light consist of discrete packets of energy, referred to as photons.

Properties of Photons

A photon of light of frequency υ contains energy E which is directly proportional to the frequency, $E = h\upsilon$.

A photon is massless (zero rest mass) and moves with the velocity of light in vacuum *i.e.*, $c = 3 \times 10^8$ m s^{-1}. It can never be brought to rest.

Photon also carry momentum p.

$$p = \frac{E}{c} = \frac{h\upsilon}{c} = \frac{h}{\lambda}$$

Intensity of photons is defined as amount of energy carried per unit area per unit time or power carried per unit area.

$$I = \frac{E}{A \times t} = \frac{P}{A}$$

By increasing the intensity of light of given wavelength, there is only an increase in the number of photons per second crossing a given area, with each photon having the same energy. Thus, photon energy is independent of intensity of radiation.

Photons are electrically neutral. Hence, they are not deflected by electric and magnetic fields.

In a photon-particle collision (such as photon-electron collision), the total energy and total momentum are conserved. However, the number of photons may not be conserved in a collision. The photon may be absorbed or a new photon may be created.

Number of photons emitted per second of frequency υ from a lamp of power P is

$$n = \frac{P}{h\upsilon} = \frac{P\lambda}{hc}$$

Electron Emission

The phenomenon of emission of electrons from the surface of a metal. The electron emission can be obtained from the following physical processes :

- **Thermionic emission :** It is the phenomenon of emission of electrons from the metal surface when heated suitably.
- **Photoelectric emission :** It is the phenomenon of emission of electrons from the surface of metal when light radiations of suitable frequency fall on it.
- **Field emission or cold cathode emission :** It is the phenomenon of emission of electrons from the surface of a metal under the application of a strong electric field.
- **Secondary emission :** It is the phenomenon of emission of electrons from the surface of metal in large number when fast moving electrons (called primary electrons) strike the metal surface.

Photoelectric Effect

The photoelectric effect, which is the emission of electrons from metals due to incident electromagnetic radiation, was first investigated in detail by Hallwachs and Lenard during 1886-1900. The explanation of these experimental results came only after Max proposed the quantum theory of radiation.

Einstein explained the photoelectric effect by applying Max planck's quantum theory.

Metals contain 'free electrons' which are free to move anywhere within the body of the metal. These 'free electrons' however, cannot escape from the body of the metal and are therefore, bound in that sense. The binding energy of these electrons with the metal varies from electron to another. The minimum binding energy of a free electron is known as the work function of the metal. It is the minimum amount of energy that is required to extract an electron from a metal.

A single photon of light can cause the emission of a single electron, and no more.

Photoelectric current

Photoelectric current depends on :

- the intensity of incident light
- the potential difference applied between the two electrodes
- the nature of the cathode material.

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Work function

The minimum energy needed by an electron to come out from a metal surface is known as work function of the metal. It is denoted by ϕ_0 and measured in electron volt (eV). The work function depends on the properties of the metal and the nature of its surface.

Stopping potential

The minimum negative potential given to anode plate with respect to cathode plate at which the photoelectric current becomes zero is known as stopping potential or cut off potential. It is denoted by V_0. If e is the charge on the photoelectron, then

$$K_{max} = eV_0 = \frac{1}{2}mv_{max}^2$$

where m is the mass of photoelectron and v_{max} is the maximum velocity of emitted photoelectrons.

The stopping potential (V_0) depends on :

- the frequency of incident light
- the nature of the cathode material.

For a given frequency of incident light, stopping potential is independent of its intensity.

Einstein's Photoelectric Equation

If a light of frequency υ is incident on a photosensitive material having work function (ϕ_0), then maximum kinetic energy of the emitted electron is given as

$$K_{max} = h\upsilon - \phi_0$$

For $\upsilon > \upsilon_0$

or $eV_0 = h\upsilon - \phi_0 = h\upsilon - h\upsilon_0$

or $eV_0 = K_{max} = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)$.

where υ_0 = threshold frequency

λ_0 = threshold wavelength

λ = incident wavelength

Einstein's photoelectric equation is in accordance with the law of conservation of energy.

The photoelectric equation explains all the features of the photoelectric effect.

Millikan's first precise measurements confirmed the Einstein's photoelectric equation and obtained an accurate value of Planck's constant h. This led to the acceptance of particle or photon description (nature) of electromagnetic radiation, introduced by Einstein.

Matter Waves (Wave Nature of Particles)

de Broglie proposed a hypothesis based on the dual nature of light. According to him, moving material particles should also behave like waves.

The wave associated with the moving particles are called matter waves or de Broglie waves. They are probability waves.

de Broglie wavelength

The de Broglie wavelength associated with a moving particle is related to its momentum as

de Broglie wavelength, $\lambda = \frac{h}{p} = \frac{h}{mv}$

where m is the mass of the particle, v is the velocity of the particle, p is the momentum of the particle.

de Broglie wavelength is independent of the charge and nature of the material particle.

If the rest mass of a particle is m_0, its de Broglie wavelength is given by

$$\lambda = \frac{h\left(1 - \frac{v^2}{c^2}\right)^{1/2}}{m_0 v}$$

In terms of kinetic energy K, de Broglie wavelength is given by $\lambda = \frac{h}{\sqrt{2mK}}$.

If a particle of charge q is accelerated through a potential difference V, its de Broglie wavelength is given by $\lambda = \frac{h}{\sqrt{2mqV}}$.

For an electron, $\lambda = \left(\frac{150}{V}\right)^{1/2}$ Å.

For a gas molecule of mass m at temperature T kelvin, its de Broglie wavelength is given by $\lambda = \frac{h}{\sqrt{3mkT}}$, where k is the Boltzmann constant.

Davisson and Germer experiment

Davisson and Germer performed an experiment to study the wave nature of electrons as suggested by de Broglie.

Electron microscope

An electron microscope is in principle similar to that of an optical microscope. In an optical microscope using visible light, focussing is done by suitable lenses whereas in an electron microscope, a beam of electrons is used in place of ordinary light and focussing is done by electrostatic and electromagnetic fields.

The wave nature of moving electrons is the basis of electron microscope.

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EXAM DRILL

1. The frequency of the incident light falling on a photosensitive metal plate is doubled, the kinetic energy of the emitted photoelectron gets
(a) doubled the earlier value
(b) unchanged
(c) more than doubled
(d) less than doubled

2. Light of wavelength 3500 Å is incident on two metals *A* and *B*, *A* of work function 4.2 eV and *B* of work function 1.19 eV respectively. The photoelectrons will be emitted by
(a) metal *A*
(b) metal *B*
(c) both *A* and *B*
(d) neither metal *A* nor metal *B*

3. If the mass of neutron = 1.7×10^{-27} kg, then the de Broglie wavelength of neutron of energy 3 eV is (Take $h = 6.6 \times 10^{-34}$ J s)
(a) 1.6×10^{-10} m (b) 1.6×10^{-11} m
(c) 1.4×10^{-10} m (d) 1.4×10^{-11} m

4. A beam of electrons of velocity 3×10^7 m s^{-1} is deflected 1.5 mm in passing 10 cm through an electric field of 1800 V m^{-1} perpendicular to their path. The value of e/m for electron is
(a) 1.78×10^{11} C kg^{-1} (b) 2×10^{11} C kg^{-1}
(c) 1.5×10^{11} C kg^{-1} (d) 3.5×10^{11} C kg^{-1}

5. In an experiment on photoelectric effect it was observed that for incident light of wavelength 1.98×10^{-7} m, stopping potential is 2.5 V. What is the work function ϕ_0 and threshold frequency?
(a) 3.75 eV, 9.1×10^{14} Hz
(b) 6.25 eV, 9.1×10^{14} Hz
(c) 6.25 eV, 8.1×10^{14} Hz
(d) 3.75 eV, 8.1×10^{14} Hz

6. A radiation is incident on a metal surface of work function 2.3 eV. The wavelength of incident radiation is 600 nm. The number of photoelectrons emitted is (Take $hc = 1240$ eV nm)
(a) zero (b) $> 10^4$
(c) $= 10^4$ (d) $< 10^4$

7. The energy that should be added to an electron to reduce its de Broglie wavelength from 1 nm to 0.5 nm is
(a) four times the initial energy
(b) equal to the initial energy
(c) twice the initial energy
(d) thrice the initial energy

8. If the work function of the photoelectric surface is 3.3 eV, then the value of threshold frequency is
(a) 8×10^{14} Hz (b) 5×10^{16} Hz
(c) 4×10^{11} Hz (d) 8×10^{10} Hz

9. The work function for Al, K and Pt is 4.28 eV, 2.30 eV and 5.65 eV respectively. Their respective threshold frequencies would be
(a) Pt > Al > K (b) Al > Pt > K
(c) K > Al > Pt (d) Al > K > Pt

10. *A* and *B* are two metals with threshold frequencies 1.8×10^{14} Hz and 2.2×10^{14} Hz. Two identical photons of energy 0.825 eV each are incident on them. Then photoelectrons are emitted in
(Take $h = 6.6 \times 10^{-34}$ J s)
(a) *B* alone (b) *A* alone
(c) neither *A* nor *B* (d) both *A* and *B*

11. The equation $E = pc$ is valid
(a) for an electron (b) for a photon
(c) for a photon as well as for an electron
(d) neither for an electron nor for a photon

12. When a light of photons of energy 4.2 eV is incident on a metallic sphere of radius 10 cm and work function 2.4 eV, photoelectrons are emitted. The number of photoelectrons liberated before the emission is stopped, is ($e = 1.6 \times 10^{-19}$ C and $\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9$ N m^{2}C^{-2})
(a) 6.25×10^8 (b) 1.25×10^9
(c) 1.25×10^8 (d) 6.25×10^{18}

13. If the momentum of an electron is changed by Δp, then the de Broglie wavelength associated with it changes by 0.50%. The initial momentum of electron will be
(a) $\frac{\Delta p}{200}$ (b) $100\Delta p$
(c) $200\Delta p$ (d) $400\Delta p$

14. If *h* is Planck's constant, the momentum of a photon of wavelength 0.01 Å is
(a) $10^{-2}h$ (b) h
(c) $10^2 h$ (d) $10^{12}h$

15. The threshold frequency of the metal of the cathode in a photoelectric cell is 1×10^{16} Hz. When a certain beam of light is incident on the cathode, it is found that a stopping potential 4.144 V is required to reduce the current to zero. The frequency of the incident radiation is (Take $h = 6.63 \times 10^{-34}$ J s)
(a) 2.5×10^{15} Hz (b) 2×10^{15} Hz
(c) 4.144×10^{15} Hz (d) 3×10^{16} Hz

16. A particle of mass $4m$ at rest decays into two particles of masses m and $3m$ having non-zero velocities. The ratio of the de Broglie wavelengths of the particles 1 and 2 is
(a) $\frac{1}{2}$ (b) $\frac{1}{4}$
(c) 2 (d) 1

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17. If λ_0 is the de Broglie wavelength for a proton accelerated through a potential difference of 100 V, the de Broglie wavelength for α-particle accelerated through the same potential difference is

(a) $2\sqrt{2}\lambda_0$ (b) $\frac{\lambda_0}{2}$

(c) $\frac{\lambda_0}{2\sqrt{2}}$ (d) $\frac{\lambda_0}{\sqrt{2}}$

18. A girl is performing a photoelectric experiment but no photoelectrons are being ejected. To eject electrons, she should change the light by

(a) decreasing the frequency
(b) increasing the frequency
(c) increasing the intensity
(d) increasing the wavelength

19. Electrons with de Broglie wavelength λ fall on the target in an X ray tube. The cut off wavelength (λ_0)of the emitted X rays is

(a) $\lambda_0 = \frac{2mc\lambda^2}{h}$ (b) $\lambda_0 = \frac{2h}{mc}$

(c) $\lambda_0 = \frac{2m^2c^2\lambda^2}{h^2}$ (d) $\lambda_0 = \lambda$

20. A photon of energy E ejects a photoelectron from a metal surface whose work function is ϕ_0. If this electron enters into a uniform magnetic field B in a direction perpendicular to the field and describes a circular path of radius r, then the radius r is given by, (in the usual notation)

(a) $\sqrt{\frac{2m(E-\phi_0)}{eB}}$ (b) $\sqrt{2m(E-\phi_0)eB}$

(c) $\frac{\sqrt{2e(E-\phi_0)}}{mB}$ (d) $\frac{\sqrt{2m(E-\phi_0)}}{eB}$

21. When a certain metal surface is illuminated with light of frequency υ, the stopping potential for photoelectric current is V_0. When the same surface is illuminated by light of frequency $\frac{\upsilon}{2}$ the stopping potential is $\frac{V_0}{4}$. The threshold frequency for photoelectric emission is

(a) $\frac{\upsilon}{6}$ (b) $\frac{\upsilon}{3}$

(c) $\frac{2\upsilon}{3}$ (d) $\frac{4\upsilon}{3}$

22. In the Davisson and Germer experiment, the velocity of electrons emitted from the electron gun can be increased by

(a) increasing the potential difference between the anode and filament
(b) increasing the filament current
(c) decreasing the filament current
(d) decreasing the potential difference between the anode and filament

23. Wave theory cannot explain the phenomena of

A. Polarization B. Diffraction
C. Compton effect D. Photoelectric effect

Which of the following is correct?

(a) A and B (b) B and D
(c) C and D (d) D and A

24. Light of wavelength λ falls on a metal having work function $\frac{hc}{\lambda_0}$. Photoelectric effect will take place only if

(a) $\lambda \geq \lambda_0$ (b) $\lambda \geq 2\lambda_0$
(c) $\lambda \leq \lambda_0$ (d) $\lambda = 4\lambda_0$

25. Given that a photon of light of wavelength 10,000 Å has an energy equal to 1.23 eV. When light of wavelength 5000 Å and intensity I_0 falls on a photoelectric cell, the surface current is 0.40×10^{-6} A and the stopping potential is 1.36 V, then the work function is

(a) 0.43 eV (b) 0.55 eV
(c) 1.10 eV (d) 1.53 eV

26. An electron of mass m and charge e initially at rest gets accelerated by a constant electric field E. The rate of change of de-Broglie wavelength of this electron at time t (ignoring relativistic effects) is

(a) $\frac{-h}{eEt^2}$ (b) $\frac{-mh}{eEt^2}$

(c) $\frac{-h}{eEt}$ (d) $\frac{-eEt}{h}$

27. Monochromatic light incident on a metal surface emits electrons with kinetic energies from zero to 2.6 eV. What is the least energy of the incident photon, if the tightly bound electron needs 4.2 eV to remove?

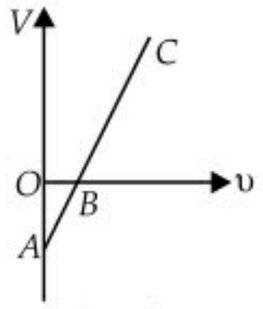
(a) 1.6 eV
(b) From 1.6 eV to 6.8 eV
(c) 6.8 eV
(d) More than 6.8 eV

28. An α-particle and proton have same kinetic energy, the ratio of de Broglie wavelength of α-particle and proton is

(a) 2 (b) 1

(c) $\frac{1}{2}$ (d) $\frac{1}{4}$

29. The stopping potential V for photoelectric emission from a metal surface is plotted along Y-axis and frequency υ of incident light along X-axis.



A straight line is obtained as shown in the figure. Planck's constant is given by

(a) slope of the line.
(b) product of slope of the line and charge on the electron.
(c) intercept along Y-axis divided by charge on the electron.
(d) product of intercept along X-axis and mass of the electron.

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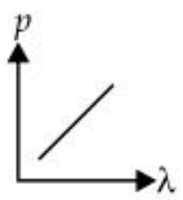
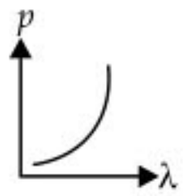
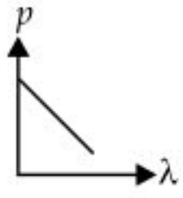
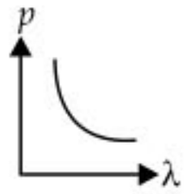
30. Which of the following figure represents the variation of particle momentum (p) and associated de Broglie wavelength (λ)?

(a) 

(b) 

(c) 

(d) 

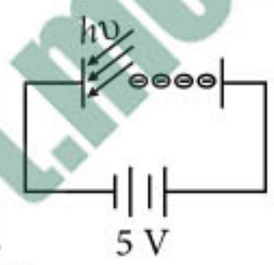
31. When photons of energy 4.28 eV strike the surface of a metal, the ejected photoelectrons have a maximum kinetic energy E_A eV and de-Broglie wavelength λ_A. The maximum kinetic energy of photoelectrons liberated from another metal B by photons of energy 4.70 eV is $E_B = (E_A - 1.50)$eV. If the de-Broglie wavelength of these photoelectrons is $\lambda_B = 2\lambda_A$, then

(a) the work function of A is 2.25 eV
(b) the work function of B is 4.28 eV
(c) $E_A = 2.0$ eV
(d) $E_B = 2.75$ eV

32. Two radiations of photon energies 1 eV and 2.5 eV, successively illuminate a photosensitive metallic surface of work function 0.5 eV. The ratio of the maximum speeds of the emitted electrons is

(a) 1 : 4 (b) 1 : 2
(c) 1 : 1 (d) 1 : 5

33. Photons of energy 5 eV are incident on cathode. Electrons reaching the anode have kinetic energies varying from 6 eV to 8 eV. Then which of the following is true?



(a) Work function of the metal is 2 eV.
(b) Work function of the metal is 3 eV.
(c) Current in the circuit is equal to saturation value.
(d) Both (a) and (c).

34. The de Broglie wavelength and kinetic energy of a particle is 2000 Å and 1 eV respectively. If its kinetic energy becomes 1 MeV, then its de Broglie wavelength becomes

(a) 1 Å (b) 5 Å
(c) 2 Å (d) 10 Å

35. A proton and an alpha particle are accelerated under the same potential difference. The ratio of de-Broglie wavelengths of the proton and the alpha particle is

(a) $\sqrt{8}$ (b) $\frac{1}{\sqrt{8}}$
(c) 1 (d) 2

36. The de Broglie wavelength of an electron moving with a velocity 1.5×10^8 m/s is equal to that of a photon. The ratio of the kinetic energy of the electron to the energy of the photon is

(a) $\frac{1}{4}$ (b) $\frac{1}{2}$
(c) 2 (d) 4

37. The threshold frequency for a certain photosensitive metal is υ_0. When it is illuminated by light of frequency $\upsilon = 2\upsilon_0$, the maximum velocity of photoelectrons is v_0. What will be the maximum velocity of the photoelectrons when the same metal is illuminated by light of frequency $\upsilon = 5\upsilon_0$?

(a) $\sqrt{2}v_0$ (b) $2v_0$
(c) $2\sqrt{2}v_0$ (d) $4v_0$

38. The work function of a certain metal is 3.31×10^{-19} J. Then, the maximum kinetic energy of photoelectrons emitted by incident radiation of wavelength 5000 Å is

(a) 2.48 eV (b) 0.42 eV
(c) 2.07 eV (d) 0.82 eV

39. Electrons ejected from the surface of a metal, when light of certain frequency is incident on it, are stopped fully by a retarding potential of 3 V. Photoelectric effect in this metallic surface begins at a frequency 6×10^{14} s^{-1}. The frequency of the incident light in s^{-1} is [Planck's constant = 6.4×10^{-34} J s, charge on the electron = 1.6×10^{-19} C]

(a) 7.5×10^{13}
(b) 13.5×10^{13}
(c) 13.5×10^{14}
(d) 7.5×10^{15}

40. A radio transmitter radiated 1 kW power at a wavelength 198.6 m. How many photons does it emit per second?

(a) 10^{10} (b) 10^{20}
(c) 10^{30} (d) 10^{40}

41. The de Broglie wavelength of an electron (mass = 1×10^{-30} kg, charge = 1.6×10^{-19} C) with a kinetic energy of 200 eV is (Planck's constant = 6.6×10^{-34} J s)

(a) 9.60×10^{-11} m
(b) 8.25×10^{-11} m
(c) 6.25×10^{-11} m
(d) 5.00×10^{-11} m

42. The work functions of Silver and Sodium are 4.6 and 2.3 eV, respectively. The ratio of the slope of the stopping potential versus frequency plot for Silver to that of Sodium is

(a) 1 : 1 (b) 1 : 2
(c) 2 : 1 (d) 1 : 4

43. For what kinetic energy of proton, will the associated de Broglie wavelength be 16.5 nm?
(Given $m_p = 1.675 \times 10^{-27}$ kg, $h = 6.63 \times 10^{-34}$ J s)

(a) 5.2×10^{-4} J
(b) 5.2×10^{-20} J
(c) 4.8×10^{-25} J
(d) 4.8×10^{-30} J

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44. In photoelectric effect, the photo-current
(a) depends both on intensity and frequency of the incident light.
(b) does not depend on the frequency of incident light but depends on the intensity of the incident light.
(c) decreases with increase in frequency of incident light.
(d) increases with increase in frequency of incident light.

45. A particle moves in a closed orbit around the origin, due to a force which is directed towards the origin. The de Broglie wavelength of the particle varies cyclically between two values λ_1 and λ_2 with $\lambda_1 > \lambda_2$. Which of the following statements is true?
(a) The particle could be moving in a circular orbit with origin as centre.
(b) The particle could be moving in an elliptic orbit with origin as its focus.
(c) When the de Broglie wavelength is λ_1, the velocity of particle is more than when its value is λ_2.
(d) Both (a) and (c)

DAY 25 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____
(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (c) : Let K_1 and K_2 be the kinetic energy of photoelectrons for incident light of frequency υ and 2υ respectively.
According to Einstein's photoelectric equation
$h\upsilon = K_1 + \phi_0$ ...(i)
and $h2\upsilon = K_2 + \phi_0$ ...(ii)
$\therefore \quad 2(K_1 + \phi_0) = K_2 + \phi_0$ or $K_2 = 2K_1 + \phi_0$
It means the kinetic energy of the photoelectrons becomes more than doubled.

2. (b): Energy of the incident light,

$$E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{3500\times10^{-10}\times1.6\times10^{-19}}\text{eV} = 3.55\text{ eV}$$

So, only B will emit photoelectrons as E > work function of B.

3. (b): Here, $E = 3\text{ eV} = 3\times1.6\times10^{-19}\text{ J}$

de Broglie wavelength, $\lambda = \frac{h}{\sqrt{2mE}}$

$$= \frac{6.6\times10^{-34}}{\sqrt{2\times1.7\times10^{-27}\times3\times1.6\times10^{-19}}} = 1.6\times10^{-11}\text{ m}$$

4. (c) : $y = \frac{1}{2}at^2 = \frac{1}{2}\frac{eE}{m}\frac{x^2}{v^2}$

$$\text{or } \frac{e}{m} = \frac{2yv^2}{Ex^2} = \frac{2\times1.5\times10^{-3}\times(3\times10^{7})^2}{1800\times(0.1)^2}$$

$= 1.5\times10^{11}\text{ C kg}^{-1}$

5. (a) : $K_{max} = eV_s = 2.5\text{ eV}$
where V_s is the stopping potential
Energy of the incident light

$$E = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{1.98\times10^{-7}}\text{J}$$

$$= \frac{6.6\times10^{-34}\times3\times10^{8}}{1.98\times10^{-7}\times1.6\times10^{-19}}\text{eV} = 6.25\text{ eV}$$

According to Einstein's photoelectric equation
$K_{max} = E - \phi_0$ where ϕ_0 is the work function
$\phi_0 = E - K_{max} = 6.25\text{ eV} - 2.5\text{ eV} = 3.75\text{ eV}$
$\phi_0 = h\upsilon_0$
where υ_0 is the threshold frequency

$$\text{or} \quad \upsilon_0 = \frac{\phi_0}{h} = \frac{3.75\times1.6\times10^{-19}}{6.6\times10^{-34}} = 9.1\times10^{14}\text{ Hz}$$

6. (a) : Energy of a photon is

$$E = \frac{hc}{\lambda} = \frac{1240\text{ eV nm}}{600\text{ nm}} = 2.07\text{ eV}$$

Since the incident energy (E = 2.07 eV) is less than work function (ϕ_0 = 2.3 eV) no photoelectrons are emitted.

7. (d): de Broglie wavelength, $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}}$ ...(i)

After decreasing wavelength,

$$\lambda' = \frac{h}{p'} = \frac{h}{\sqrt{2mE'}} \quad \text{...(ii)}$$

From eqs. (i) and (ii),

$$\frac{\lambda'}{\lambda} = \sqrt{\frac{E}{E'}}$$

Putting values of λ' and λ, we get

$$\frac{E}{E'} = \left(\frac{0.5}{1}\right)^2 \quad \therefore \quad E' = \frac{E}{0.25} = 4E$$

The energy should be added to decrease the wavelength
$= E' - E = 4E - E = 3E$.

8. (a) : Here, $\phi_0 = 3.3\text{ eV} = 3.3\times1.6\times10^{-19}\text{ J}$
Work function, $\phi_0 = h\upsilon_0$
where υ_0 is the threshold frequency

$$\upsilon_0 = \frac{\phi_0}{h} = \frac{3.3\times1.6\times10^{-19}\text{ J}}{6.6\times10^{-34}\text{ J s}}$$

$= 0.8\times10^{15}\text{ Hz} = 8\times10^{14}\text{ Hz}$

9. (a) : Work function, $\phi_0 = h\upsilon_0$
where υ_0 = Threshold frequency
So, $\phi_0 \propto \upsilon_0$
Hence Pt > Al > K

10. (b): $\phi_{0A} = \frac{h\upsilon_0}{e}\text{eV} = \frac{(6.6\times10^{-34})\times(1.8\times10^{14})}{1.6\times10^{-19}}\text{eV} = 0.74\text{ eV}$

$$\phi_{0B} = \frac{(6.6\times10^{-34})\times(2.2\times10^{14})}{1.6\times10^{-19}}\text{eV} = 0.91\text{ eV}$$

Since the incident energy 0.825 eV is greater than 0.74 eV and less than 0.91 eV, so photoelectrons are emitted from metal A only.

11. (b): According to relativistic formula
$E^2 = (pc)^2 + (m_0c^2)^2$
For photon, $m_0 = 0$
$\therefore \quad E = pc$

12. (c) : Here,
Radius of the sphere, $r = 10\text{ cm} = 10\times10^{-2}\text{ m}$
Work function, $\phi_0 = 2.4\text{ eV}$
Energy of a photon, $E = h\upsilon = 4.2\text{ eV}$
According to Einstein's photoelectric equation
$h\upsilon = \phi_0 + eV_s$
$4.2\text{ eV} = 2.4\text{ eV} + eV_s$
$eV_s = 4.2\text{ eV} - 2.4\text{ eV} = 1.8\text{ eV} \quad \therefore \quad V_s = 1.8\text{ V}$
The sphere will stop emitting photoelectrons, when the potential on its surface becomes 1.8 V.
Let N be the number of photoelectrons emitted from the sphere. Then,
Charge on the sphere, $Q = Ne$

$$V_S = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r} = \frac{1}{4\pi\varepsilon_0}\frac{Ne}{r}$$

$$N = \frac{V_S\times r}{\frac{1}{4\pi\varepsilon_0}\times e} = \frac{1.8\times r}{\frac{1}{4\pi\varepsilon_0}\times e} = \frac{1.8\times10\times10^{-2}}{9\times10^{9}\times1.6\times10^{-19}}$$

$$= \frac{18}{16}\times\frac{1}{9}\times10^{9} = 1.25\times10^{8}$$

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13. (c) : de Broglie wavelength, $\lambda = \frac{h}{p}$

$$\therefore \quad d\lambda = -\frac{h}{p^2}dp; \quad \frac{d\lambda}{\lambda} = \frac{-\frac{h}{p^2}dp}{\frac{h}{p}} = -\frac{dp}{p}$$

$$\frac{d\lambda}{\lambda} = \frac{dp}{p}\text{(in magnitude)}$$

Given $\frac{d\lambda}{\lambda} = \frac{0.5}{100}$; $dp = \Delta p$

Let the initial momentum be p_0.

Then $\frac{\Delta p}{p_0} = \frac{d\lambda}{\lambda} = \frac{0.5}{100}$ or $p_0 = \frac{100}{0.5}\Delta p = 200\Delta p$

14. (d): Momentum of photon, $p = \frac{E}{c} = \frac{h\upsilon}{c}$

Where E is the energy of a photon and c is the velocity of light.

$$\therefore \quad p = \frac{hc}{c\lambda} \qquad \left[\because \quad \upsilon = \frac{c}{\lambda}\right]$$

$$= \frac{h}{\lambda} = \frac{h}{0.01\times10^{-10}} = 10^{12}h$$

15. (b): Here,

Threshold frequency, $\upsilon_0 = 1\times10^{15}$ Hz

Stopping potential, $V_s = 4.144$ V

Work function, $\phi_0 = h\upsilon_0$

$$= \frac{6.63\times10^{-34}\times1\times10^{15}}{1.6\times10^{-19}}\text{eV} = 4.144\text{ eV}$$

According to Einstein's photoelectric equation

$h\upsilon = \phi_0 + eV_s$

= 4.144 eV + 4.144 eV= 8.288 eV

Energy of incident photon, $E = h\upsilon = 8.288$ eV

$\therefore$ Frequency of incident photon,

$$\upsilon = \frac{E}{h} = \frac{8.288\times1.6\times10^{-19}\text{ J}}{6.63\times10^{-34}\text{ J s}} = 2\times10^{15}\text{Hz}$$

16. (d): According to law of conservation of linear momentum, two particles will have equal and opposite momentum.

The de Broglie wavelength is given by

$$\lambda = \frac{h}{p} \qquad \therefore \quad \frac{\lambda_1}{\lambda_2} = 1$$

17. (c) : Kinetic energy gained by a charge q after being accelerated through a potential difference V is given by

$$qV = \frac{1}{2}mv^2; \quad v = \sqrt{\frac{2qV}{m}} \text{ and } mv = \sqrt{2mqV}$$

de Broglie wavelength, $\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2mqV}}$

For a proton, $\lambda_p = \frac{h}{\sqrt{2m_pq_pV_p}}$

For an α-particle

$$\lambda_\alpha = \frac{h}{\sqrt{2m_\alpha q_\alpha V_\alpha}} \qquad \therefore \quad \frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_pq_pV_p}{m_\alpha q_\alpha V_\alpha}}$$

$V_\alpha = V_p = 100$ V (Given)

$$\therefore \quad \frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_pq_p}{m_\alpha q_\alpha}} = \sqrt{\frac{m_pq_p}{(4m_p)(2q_p)}} = \sqrt{\frac{1}{8}} = \frac{1}{2\sqrt{2}}$$

$$\lambda_\alpha = \frac{\lambda_p}{2\sqrt{2}} = \frac{\lambda_0}{2\sqrt{2}} \qquad (\because \quad \lambda_p = \lambda_0 \text{ (Given)})$$

18. (b)

19. (a) : Let K be the kinetic energy of the incident electron.

Its linear momentum, $p = \sqrt{2mK}$

The de Broglie wavelength is related to the linear momentum as

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mK}} \text{ or } K = \frac{h^2}{2m\lambda^2}$$

The cut off wavelength of the emitted X rays is related to the kinetic energy of the incident electron as

$$\frac{hc}{\lambda_0} = K = \frac{h^2}{2m\lambda^2} \quad \text{or} \quad \lambda_0 = \frac{2mc\lambda^2}{h}$$

20. (d): As the electron describes a circular path of radius r in the magnetic field, therefore

$$\frac{mv^2}{r} = evB; \quad r = \frac{mv}{eB} = \frac{p}{eB} = \frac{\sqrt{2mK}}{eB} \qquad (\text{As } K = \frac{p^2}{2m})$$

From Einstein's photoelectric equation

$K = E - \phi_0$

$$\therefore \quad r = \frac{\sqrt{2m(E-\phi_0)}}{eB}$$

21. (b): According to Einstein's photoelectric equation

$K_{max} = h\upsilon - \phi_0$

where υ is the incident frequency and ϕ_0 is the work function of the metal.

As $K_{max} = eV_0$

where V_0 is the stopping potential

Therefore, $eV_0 = h\upsilon - \phi_0$ ...(i)

and $e\frac{V_0}{4} = h\frac{\upsilon}{2} - \phi_0$ ...(ii)

From (i) and (ii), we get

$$\frac{h\upsilon}{4} - \frac{\phi_0}{4} = \frac{h\upsilon}{2} - \phi_0 \text{ or } \phi_0 - \frac{\phi_0}{4} = \frac{h\upsilon}{2} - \frac{h\upsilon}{4}$$

$$\frac{3}{4}\phi_0 = \frac{h\upsilon}{4} \text{ or } \phi_0 = \frac{h\upsilon}{3}$$

$\therefore$ Threshold frequency,

$$\upsilon_0 = \frac{\phi_0}{h} = \frac{h\upsilon}{3}\times\frac{1}{h} = \frac{\upsilon}{3}$$

22. (a)

23. (c) : Wave theory explains the phenomena of interference, diffraction and polarization but it can't explain the photoelectric effect and Compton effect.

24. (c) : According to Einstein's photoelectric equation

$$K = \frac{hc}{\lambda} - \frac{hc}{\lambda_0}$$

K is positive, *i.e.*, photoelectric emission will take place if

$\frac{hc}{\lambda} \geq \frac{hc}{\lambda_0}$ or $\lambda \leq \lambda_0$.

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25. (c) : Energy of a photon $E = \frac{hc}{\lambda}$

or $E \propto \frac{1}{\lambda}$ $\therefore$ $\frac{E_2}{E_1} = \frac{\lambda_1}{\lambda_2}$

or $E_2 = E_1 \times \frac{\lambda_1}{\lambda_2} = 1.23 \times \frac{10000}{5000} = 2.46$ eV

According to Einstein's photoelectric equation

$h\upsilon - \phi_0 = \frac{1}{2} m v_{max}^2 = eV_s$

or $\phi_0 = h\upsilon_2 - eV_s = E_2 - eV_s = 2.46 - 1.36 = 1.10$ eV

26. (a) : Here, $u = 0$, $a = \frac{eE}{m}$

$\therefore$ $v = u + at = 0 + \frac{eE}{m}t$

de-Broglie wavelength,

$\lambda = \frac{h}{mv} = \frac{h}{m(eEt/m)} = \frac{h}{eEt}$

Rate of change of de-Broglie wavelength

$\frac{d\lambda}{dt} = \frac{h}{eE}\left(-\frac{1}{t^2}\right) = \frac{-h}{eEt^2}$

27. (c) : Maximum KE = 2.6 eV,
Work function, $\phi_0 = 4.2$ eV
Energy of incident photon = Maximum KE + ϕ_0
= 2.6 + 4.2 = 6.8 eV

28. (c) : Kinetic energy K is related with momentum (p) of the particle by the relation, $K = \frac{p^2}{2m}$

or $p = \sqrt{2mK}$

$\therefore$ de Broglie wavelength $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mK}}$;

So $\lambda \propto \frac{1}{\sqrt{m}}$

$\therefore$ $\frac{\lambda_\alpha}{\lambda_P} = \sqrt{\frac{m_P}{m_\alpha}} = \sqrt{\frac{1}{4}} = \frac{1}{2}$

29. (b): According to Einstein's photoelectric equation
$K = eV = h\upsilon - W_0$

or $V = \frac{h}{e}\upsilon - \frac{W_0}{e}$

$\therefore$ Slope of straight line between V and υ is $\frac{h}{e}$.

$\therefore$ $h = e \times$ slope of straight line.

30. (d): de Broglie wavelength, $\lambda = \frac{h}{p}$, *i.e.* $\lambda \propto \frac{1}{p}$.

31. (c) : As, $\lambda = \frac{h}{\sqrt{2mE}}$; so $\frac{\lambda_B}{\lambda_A} = \sqrt{\frac{E_A}{E_B}}$

or $2 = \sqrt{\frac{E_A}{E_B}}$ or $E_A = 4E_B$

or $\frac{E_A}{4} = E_A - 1.5$ or $E_A = 2.0$ eV

$\phi_A = 4.28 - 2.00 = 2.28$ eV
$\phi_B = 4.70 - 0.50 = 4.20$ eV

32. (b): According to Einstein's photoelectric equation

$\frac{1}{2} m v_{max}^2 = h\upsilon - \phi_0$

where $\frac{1}{2} m v_{max}^2$ is the maximum kinetic energy of the emitted electrons, $h\upsilon$ is the incident energy and ϕ_0 is the work function of the metal.

$\therefore$ $\frac{1}{2} m v_{max_1}^2 = 1$ eV $- 0.5$ eV $= 0.5$ eV ...(i)

and $\frac{1}{2} m v_{max_2}^2 = 2.5$ eV $- 0.5$ eV $= 2$ eV ...(ii)

Divide (i) and (ii), we get

$\frac{v_{max_1}^2}{v_{max_2}^2} = \frac{0.5}{2}$; $\frac{v_{max_1}}{v_{max_2}} = \sqrt{\frac{0.5}{2}} = \frac{1}{2}$

33. (a) : Maximum kinetic energy,
$K_{max} = (5 - \phi)$ eV
When these electrons are accelerated through 5 V, they will reach the anode with maximum energy = $(5 - \phi + 5)$ eV
$\therefore$ $10 - \phi = 8$ or $\phi = 2$ eV
Current is less than saturation current because even if slowest electron reaches the plate it will have 5 eV energy at the anode, but there it is given that the minimum energy is 6 eV.

34. (c) : As $\lambda = \frac{h}{\sqrt{2mK}}$
Since mass of the particle remains constant

$\therefore$ $\lambda \propto \frac{1}{\sqrt{K}}$

$\frac{\lambda'}{\lambda} = \sqrt{\frac{K}{K'}} = \sqrt{\frac{1\,\text{eV}}{1 \times 10^6\,\text{eV}}} = \frac{1}{10^3}$

or $\lambda' = \frac{\lambda}{10^3} = \frac{2000}{10^3}$ Å $= 2$ Å

35. (a) : When a charged particle of charge q and mass m is accelerated under a potential difference V, let v be velocity acquired by the particle.
Then

$qV = \frac{1}{2} mv^2$ or $mv = \sqrt{2mqV}$

de Broglie wavelength, $\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2mqV}}$

$\lambda \propto \frac{1}{\sqrt{mq}}$ for the same value of V.

$\therefore$ $\frac{\lambda_p}{\lambda_\alpha} = \frac{\sqrt{m_\alpha q_\alpha}}{\sqrt{m_p q_p}} = \sqrt{\frac{4m}{m} \times \frac{2e}{e}} = \sqrt{8}$

36. (a) : de Broglie wavelength of an electron,

$\lambda_e = \frac{h}{m_e v_e}$

where h is the Plank's constant, m_e and v_e is the mass and velocity of the electron respectively.
Wavelength of a photon = λ_{ph}
As per question

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$$\lambda_{ph} = \lambda_e = \frac{h}{m_e v_e} \quad \ldots(i)$$

Kinetic energy of the electron,

$$K_e = \frac{1}{2} m_e v_e^2 \quad \ldots(ii)$$

Energy of the photon,

$$E_{ph} = \frac{hc}{\lambda_{ph}} \quad \ldots(iii)$$

Divide (ii) by (iii), we get

$$\frac{K_e}{E_{ph}} = \frac{\frac{1}{2} m_e v_e^2}{\frac{hc}{\lambda_{ph}}} = \frac{1}{2}\frac{m_e v_e^2 \lambda_{ph}}{hc} = \frac{1}{2}\frac{m_e v_e^2 h}{hcm_e v_e} \quad \text{(Using(i))}$$

$$= \frac{1}{2}\frac{v_e}{c} = \frac{1.5\times10^8 \text{ m/s}}{2\times3\times10^8 \text{ m/s}} = \frac{1}{4}$$

37. (b): As υ_0 is the threshold frequency.

$\therefore$ Work function, $\phi_0 = h\upsilon_0$

According to Einstein photoelectric equation

$$\frac{1}{2} m v_{max}^2 = h\upsilon - \phi_0$$

where $h\upsilon$ is the incident energy, ϕ_0 is the work function of the metal and $\frac{1}{2} m v_{max}^2$ is the maximum kinetic energy of the emitted photoelectron.

As per question

$$\frac{1}{2} m v_0^2 = h(2\upsilon_0) - h\upsilon_0 = h\upsilon_0 \quad \ldots(i)$$

and $$\frac{1}{2} m v'^2 = h(5\upsilon_0) - h\upsilon_0 = 4h\upsilon_0 \quad \ldots(ii)$$

Divide (ii) by (i), we get

$$\frac{v'^2}{v_0^2} = \frac{4}{1}$$

$$v'^2 = 4v_0^2 \text{ or } v' = 2v_0$$

38. (b): Here, work function, $\phi_0 = 3.31 \times 10^{-19}$ J

Wavelength, $\lambda = 5000$ Å $= 5000 \times 10^{-10}$ m

Energy of the incident photon,

$$E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^8}{5000\times10^{-10}} = 3.98 \times 10^{-19} \text{ J}$$

According to Einstein's photoelectric equation

$$K_{max} = h\upsilon - \phi_0 = 3.98 \times 10^{-19} \text{ J} - 3.31 \times 10^{-19} \text{ J}$$
$$= 0.67 \times 10^{-19} \text{ J}$$
$$= \frac{0.67\times10^{-19}}{1.6\times10^{-19}} \text{ eV} = 0.42 \text{ eV}$$

39. (c) : The maximum kinetic energy of emitted photoelectrons

$K_{max} = eV_s = e(3 \text{ V}) = 3$ eV

Work function, $\phi_0 = h\upsilon_0 = (6.4 \times 10^{-34})(6 \times 10^{14})$ J

$$= \frac{(6.4\times10^{-34})(6\times10^{14})}{1.6\times10^{-19}} \text{ eV} = 2.4 \text{ eV}$$

According to Einstein's photoelectric equation

$h\upsilon = K_{max} + \phi_0$ where $h\upsilon$ is incident energy

$h\upsilon = 3$ eV + 2.4 eV = 5.4 eV

$\therefore$ The frequency of the incident light is

$$\upsilon = \frac{5.4 \text{ eV}}{h} = \frac{5.4\times1.6\times10^{-19} \text{ J}}{6.4\times10^{-34} \text{ J s}} = 13.5\times10^{14} \text{ s}^{-1}$$

40. (c) : Here, number of photons emitted per second,

$$n = \frac{P}{E} = \frac{P}{h\upsilon} = \frac{P\lambda}{hc} \quad \left(\because \upsilon = \frac{c}{\lambda}\right) = \frac{1000\times198.6}{6.6\times10^{-34}\times3\times10^8} = 10^{30}.$$

41. (b): de Broglie wavelength associated with charged particle

$$\lambda = \frac{h}{\sqrt{2mE}}$$

Here, $m = 1 \times 10^{-30}$ kg, $e = 1.6 \times 10^{-19}$ C

$E = 200$ eV and $h = 6.6 \times 10^{-34}$ J s

$$\therefore \quad \lambda = \frac{6.6\times10^{-34}}{\sqrt{2\times1\times10^{-30}\times200\times1.6\times10^{-19}}}$$

$$= \frac{6.6}{8} \times \frac{10^{-34}}{10^{-24}} = 8.25 \times 10^{-11} \text{ m}.$$

42. (a) : According to Einstein's photoelectric equation

$K_{max} = h\upsilon - \phi_0$

where the symbols have their usual meaning.

But $K_{max} = eV_s$ where V_s is the stopping potential

$$V_s = \frac{h}{e}\upsilon - \frac{\phi_0}{e}$$

Thus, the graph between $V_s - \upsilon$ is a straight line.

Compare the above relation with $y = mx + C$

$\therefore$ Slope of $V_s - \upsilon$ graph $= \frac{h}{e}$

It is same for both the metals.

$\therefore$ Ratio of the slopes = 1.

43. (c) : Kinetic energy of proton, $K = \frac{1}{2} mv^2$

$$= \frac{1}{2m}(mv)^2 = \frac{1}{2m}\left(\frac{h^2}{\lambda^2}\right) \quad \left(\because \lambda = \frac{h}{p}\right)$$

$$= \frac{(6.63\times10^{-34})^2}{2\times1.675\times10^{-27}\times(16.5\times10^{-9})^2} = 4.82 \times 10^{-25} \text{ J}$$

44. (b): Photocurrent depends on the intensity of the incident light and is independent of the frequency of incident light.

45. (b): The de Broglie wavelength of the particle can be varying cyclically between two values λ_1 and λ_2, if particle is moving in an elliptical orbit with origin as its one focus.

Let v_1, v_2 be the speed of particle at A and B respectively and origin is at focus O. If λ_1, λ_2 are the de Broglie wavelengths associated with particle while moving at A and B respectively.

Then

$$\lambda_1 = \frac{h}{mv_1} \text{ and } \lambda_2 = \frac{h}{mv_2} \quad \therefore \quad \frac{\lambda_1}{\lambda_2} = \frac{v_2}{v_1}$$

Since $\lambda_1 > \lambda_2 \quad \therefore \quad v_2 > v_1$

Thus, option (b) is true.

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Atoms

Thomson Atomic Model

J J Thomson proposed an atomic model which is called apple pie pudding model of atom.

According to this model, an atom is made up of positively charged substance which is spread very thiny in the form of a sphere. Into this sphere are embedded negatively charged electrons, much the same way as pieces of apple are embedded in the apple pie. Further, it was assumed that total positive charge is equal to total negative charge, therefore, the atom remains electrically neutral.

J J Thomson's model of atom was not accepted by fellow physicists, as it was unable to explain how positively charged particles are shielded from the negatively charged particles, without getting neutralised.

Rutherford Atomic Model

Electrons (negatively charged like particles) revolve around a fixed positively charged central nucleus in different orbits, just like the planets attraction. The coulombic force between electron and nucleus provides the necessary centripetal acceleration. The orbits of revolution of the electrons are circular.

Rutherford's Scattering Formula

- The formula that Rutherford obtained for alpha particle scattering by a thin foil on the basis of the Rutherford's nuclear model of the atom is given by

$$N(\theta) = \frac{N_i n t Z^2 e^4}{(8\pi\varepsilon_0)^2 r^2 K^2 \sin^4(\theta/2)}$$

where $N(\theta)$ = number of alpha particles per unit area that reach the screen at a scattering angle of θ

N_i = total number of alpha particles that reach the screen

n = number of atoms per unit volume in the foil

Z= atomic number of the foil atoms

r = distance of the screen from the foil

K = kinetic energy of the alpha particles

t = foil thickness

- The fraction of incident alpha particles scattered by an angle θ or greater is

$$f = \pi n t \left(\frac{Ze^2}{4\pi\varepsilon_0 K}\right)^2 \cot^2\frac{\theta}{2}$$

Impact Parameter

It is defined as the perpendicular distance of the initial velocity vector of the alpha particle from the central line of the nucleus, when the particle is far away from the nucleus of the atom. The scattering angle θ of the α particle and impact parameter b are related as

$$b = \frac{Ze^2 \cot(\theta/2)}{4\pi\varepsilon_0 K}$$

where K is the kinetic energy of the α particle and Z is the atomic number of the nucleus.

Smaller the impact parameter, larger the angle of scattering θ.

Distance of Closest Approach

- At the distance of closest approach whole of the kinetic energy of the alpha particles is converted into a potential energy.
- Distance of closest approach; $r_0 = \frac{2Ze^2}{4\pi\varepsilon_0 K}$

Bohr's Model

Bohr introduced the concept of radiation orbits to overcome the difficulty of radiation of energy by an accelerating electron in an atom.

An analysis of the hydrogen spectrum indicated that the energy of an electron in an atom can have certain stationary values only. He postulated that the electron moves around a nucleus in certain fixed circular paths in which it does not radiate (lose) energy. Therefore, the energy of an electron in a radiationless orbit would remain constant.

Bohr numbered the corresponding orbits by means of an integer n(1, 2, 3, etc). These are known as principal quantum numbers. The electron cannot move in any circular path other than these orbits.

Angular momentum of the electron in a stationary orbit is an integral multiple of $h/2\pi$.

i.e., $L = \frac{nh}{2\pi}$ or, $mvr = \frac{nh}{2\pi}$

This is known as Bohr's quantisation condition, where m is the mass of the electron, v is the velocity of the electron, r is the radius of the orbit and n is an positive integer known as principal quantum number.

This postulate is equivalent to saying that in a stationary state, the circumference of a circular orbit contains integral numbers of de Broglie wavelength.

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$$2\pi r = n\lambda = \frac{nh}{mv} \quad i.e.\ L = mvr = \frac{nh}{2\pi}.$$

The emission of radiation takes place when an electron makes a transition from a higher to a lower orbit. The frequency of the radiation is given by

$$\upsilon = \frac{E_2 - E_1}{h}$$

where E_2 and E_1 are the energies of the electron in the higher and lower orbits respectively.

Since the centripetal force for circular orbit is provided by the Coulomb's force, we have

$$\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r^2} = \frac{mv^2}{r}$$

where Z is the atomic number of the element and e is the electronic charge.

Bohr's Formulae

- Radius of n^{th} orbit

$$r_n = \frac{4\pi\varepsilon_0 n^2 h^2}{4\pi^2 mZe^2}; \quad r_n = \frac{0.53n^2}{Z}\ \text{Å}$$

- Velocity of electron in the n^{th} orbit

$$v_n = \frac{1}{4\pi\varepsilon_0}\frac{2\pi Ze^2}{nh} = \frac{2.2\times10^6\ Z}{n}\ \text{m s}^{-1}$$

- The kinetic energy of the electron in the n^{th} orbit

$$K_n = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2r_n} = \left(\frac{1}{4\pi\varepsilon_0}\right)^2\frac{2\pi^2 me^4Z^2}{n^2h^2} = \frac{13.6Z^2}{n^2}\ \text{eV}$$

- The potential energy of electron in n^{th} orbit

$$U_n = -\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r_n} = -\left(\frac{1}{4\pi\varepsilon_0}\right)^2\frac{4\pi^2 me^4Z^2}{n^2h^2} = \frac{-27.2Z^2}{n^2}\ \text{eV}$$

- Total energy of electron in n^{th} orbit

$$E_n = U_n + K_n = -\left(\frac{1}{4\pi\varepsilon_0}\right)^2\frac{2\pi^2 me^4Z^2}{n^2h^2} = -\frac{13.6Z^2}{n^2}\ \text{eV}$$

- Frequency of electron in n^{th} orbit

$$\upsilon_n = \left(\frac{1}{4\pi\varepsilon_0}\right)^2\frac{4\pi^2Z^2e^4m}{n^3h^3} = \frac{6.62\times10^{15}Z^2}{n^3}$$

- Wavelength of radiation in the transition from $n_2 \to n_1$ is given by; $\frac{1}{\lambda} = RZ^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$

where R is called Rydberg's constant.

$$R = \left(\frac{1}{4\pi\varepsilon_0}\right)^2\frac{2\pi^2me^4}{ch^3} = 1.097\times10^7\ \text{m}^{-1}$$

Spectral Series of Hydrogen Atom

When the electron in a H atom jumps from higher energy level to lower energy level, the difference of energies of the two energy levels is emitted as radiation of particular wavelength, known as spectral line. Spectral lines of different wavelengths are obtained for transition of electron between two different energy levels, which are found to fall in a number of spectral series given by

Lyman Series

- Emission spectral lines corresponding to the transition of electron from higher energy levels (n_2 = 2, 3, ...,∞) to first energy level (n_1 = 1) constitute Lyman series.

$$\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{n_2^2}\right]$$

where n_2 = 2, 3, 4, ...,∞

- Series limit line (shortest wavelength) of Lyman series is given by

$$\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{\infty^2}\right] = R \quad \text{or} \quad \lambda = \frac{1}{R}$$

- The first line (longest wavelength) of the Lyman series is given by

$$\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{2^2}\right] = \frac{3R}{4} \quad \text{or} \quad \lambda = \frac{4}{3R}$$

- Lyman series lies in the ultraviolet region of electromagnetic spectrum.
- Lyman series is obtained in emission as well as in absorption spectrum.

Balmer Series

- Emission spectral lines corresponding to the transition of electron from higher energy levels (n_2 = 3, 4, ...∞) to second energy level (n_1 = 2) constitute Balmer series.

$$\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{n_2^2}\right]$$

where n_2 = 3, 4, 5.....,∞

- Series limit line (shortest wavelength) of Balmer series is given by

$$\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{\infty^2}\right] = \frac{R}{4} \quad \text{or} \quad \lambda = \frac{4}{R}$$

- The first line (longest wavelength) of the Balmer series is given by

$$\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{3^2}\right] = \frac{5R}{36} \quad \text{or} \quad \lambda = \frac{36}{5R}$$

- Balmer series lies in the visible region of electromagnetic spectrum.
- This series is obtained only in emission spectrum.

Paschen Series

- Emission spectral lines corresponding to the transition of electron from higher energy levels (n_2 = 4, 5, ...,∞) to third energy level (n_1 = 3) constitute Paschen series.

$$\frac{1}{\lambda} = \frac{1}{R}\left[\frac{1}{3^2} - \frac{1}{n_2^2}\right]$$

where n_2 = 4, 5, 6.....,∞

- Series limit line (shortest wavelength) of the Paschen series is given by

$$\frac{1}{\lambda} = R\left[\frac{1}{3^2} - \frac{1}{\infty^2}\right] = \frac{R}{9} \quad \text{or} \quad \lambda = \frac{9}{R}$$

- The first line (longest wavelength) of the Paschen series is given by

$$\frac{1}{\lambda} = R\left[\frac{1}{3^2} - \frac{1}{4^2}\right] = \frac{7R}{144} \quad \text{or} \quad \lambda = \frac{144}{7R}$$

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- Paschen series lies in the infrared region of electromagnetic spectrum.
- This series obtained only in the emission spectrum.

Brackett Series

- Emission spectral lines corresponding to the transition of electron from higher energy levels ($n_2 = 5, 6, 7,.....,\infty$) to fourth energy level ($n_1 = 4$) constitute Brackett series.

$$\frac{1}{\lambda} = R\left[\frac{1}{4^2} - \frac{1}{n_2^2}\right]$$

where $n_2 = 5, 6, 7.....,\infty$

- Series limit line (shortest wavelength) of Brackett series is given by

$$\frac{1}{\lambda} = R\left[\frac{1}{4^2} - \frac{1}{\infty^2}\right] = \frac{R}{16} \quad \text{or} \quad \lambda = \frac{16}{R}$$

- The first line (longest wavelength) of Brackett series is given by

$$\frac{1}{\lambda} = R\left[\frac{1}{4^2} - \frac{1}{5^2}\right] = \frac{9R}{400} \quad \text{or} \quad \lambda = \frac{400}{9R}$$

- Brackett series lies in the infrared region of electromagnetic spectrum.
- This series is obtained only in the emission spectrum.

Pfund Series

- Emission spectral lines corresponding to the transition of electron from higher energy levels ($n_2 = 6, 7, 8,.....,\infty$) to fifth energy level ($n_1 = 5$) constitute Pfund series.

$$\frac{1}{\lambda} = R\left[\frac{1}{5^2} - \frac{1}{n_2^2}\right]$$

where $n_2 = 6, 7,.....,\infty$

- Series limit line (shortest wavelength) of Pfund series is given by

$$\frac{1}{\lambda} = R\left[\frac{1}{5^2} - \frac{1}{\infty^2}\right] = \frac{R}{25} \quad \text{or} \quad \lambda = \frac{25}{R}$$

- The first line (longest wavelength) of the Pfund series is given by

$$\frac{1}{\lambda} = R\left[\frac{1}{5^2} - \frac{1}{6^2}\right] = \frac{11R}{900} \quad \text{or} \quad \lambda = \frac{900}{11R}$$

- Pfund series also lies in the infrared region of electromagnetic spectrum.
- This series is obtained only in the emission spectrum.
- Number of spectral lines due to transition of electron from n^{th} orbit to lower orbit is

$$N = \frac{n(n-1)}{2}$$

Ionization energy and ionization potential

- Ionization energy $= \frac{13.6Z^2}{n^2}$ eV
- Ionization potential $= \frac{13.6Z^2}{n^2}$ volt

Energy Quantisation

In quantum mechanics, the energies of a system are discrete or quantised. The energy of a particle of mass m is confined to a box of length L can have only discrete values of energy given by the relation

$$E_n = \frac{n^2h^2}{8mL^2} \text{ where } n = 1, 2, 3, ...$$

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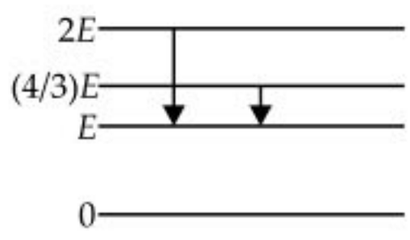
EXAM DRILL

1. The ionisation potential of hydrogen atom is 13.6 V. The energy required to remove an electron from the second orbit of hydrogen will be
(a) 27.4 eV (b) 13.6 eV
(c) 3.4 eV (d) 10.2 eV

2. The wavelength of the first line of Lyman series for hydrogen atom is equal to that of the second line of Balmer series for a hydrogen like ion. The atomic number Z of hydrogen like ion is
(a) 3 (b) 4 (c) 1 (d) 2

3. The binding energy of an electron in the ground state of He is equal to 24. 6 eV. The energy required to remove both the electrons is
(a) 49.2 eV (b) 24.6 eV
(c) 38.2 eV (d) 79.0 eV

4. The figure indicates the energy levels of a certain atom. When the system moves from $2E$ level to E, a photon of wavelength λ is emitted.



The wavelength of photon produced during its transition from $\frac{4E}{3}$ level to E is
(a) $\frac{\lambda}{3}$ (b) $\frac{3\lambda}{4}$ (c) $\frac{4\lambda}{3}$ (d) 3λ

5. If the binding energy of the electron in a hydrogen atom is 13.6 eV, the energy required to remove the electron from the first excited state of Li^{++} is
(a) 122.4 eV (b) 30.6 eV
(c) 13.6 eV (d) 3.4 eV

6. If λ_1 and λ_2 are the wavelengths of the first members of the Lyman and Paschen series respectively, then $\lambda_1 : \lambda_2$ is
(a) 1 : 3 (b) 1 : 30 (c) 7 : 50 (d) 7 : 108

7. The minimum energy in electron volt required to strip a ten times ionised sodium atom (*i.e.*, $Z = 11$) of its last electron is
(a) 13.6 (b) $\frac{13.6}{11}$
(c) 13.6×11 (d) $13.6 \times (11)^2$

8. The total energy of an electron in the excited state corresponding to $n = 3$ state is E. What is its potential energy with proper sign?
(a) $-2E$ (b) $2E$ (c) $-E$ (d) E

9. In Bohr theory of hydrogen atom, let r, v and E be the radius of orbit, speed of electron and the total energy of the electron respectively. Which of the following quantities is proportional to the quantum number n?
(a) vr (b) rE (c) $\frac{r}{E}$ (d) $\frac{r}{v}$

10. In Bohr model of hydrogen atom, the ratio of period of revolution of an electron in $n = 2$ and $n = 1$ orbit is
(a) 2 : 1 (b) 4 : 1 (c) 8 : 1 (d) 16 : 1

11. A hydrogen atom and a Li^{2+} ion are both in the second excited state. If l_H and l_{Li} are their respective electronic angular momenta, and E_H and E_{Li} their respective energies, then
(a) $l_H > l_{Li}$ and $|E_H| > |E_{Li}|$
(b) $l_H = l_{Li}$ and $|E_H| < |E_{Li}|$
(c) $l_H = l_{Li}$ and $|E_H| > |E_{Li}|$
(d) $l_H < l_{Li}$ and $|E_H| < |E_{Li}|$

12. The ratio of the longest and shortest wavelengths in Brackett series of hydrogen spectra is
(a) $\frac{25}{9}$ (b) $\frac{17}{6}$ (c) $\frac{9}{5}$ (d) $\frac{4}{3}$

13. The electric potential between a proton and an electron is given by $V = V_0 \ln\left(\frac{r}{r_0}\right)$, where r_0 is a constant. Assuming Bohr's model to be applicable, write variation of r_n with n, n being the principal quantum number
(a) $r_n \propto n$ (b) $r_n \propto \frac{1}{n}$ (c) $r_n \propto n^2$ (d) $r_n \propto \frac{1}{n^2}$

14. A hydrogen atom is excited up to 9th level. The total number of possible spectral lines emitted by the hydrogen atom is
(a) 36 (b) 35 (c) 37 (d) 38

15. The radius of the hydrogen atom in its ground state is a_0. The radius of a muonic hydrogen atom in which the electron is replaced by an identically charged muon with mass 207 times that of an electron, is a_μ equal to
(a) $207a_0$ (b) $\frac{a_0}{207}$ (c) $\frac{a_0}{\sqrt{207}}$ (d) $a_0\sqrt{207}$

16. Which energy state of doubly ionised lithium has the same energy as that of the ground state of hydrogen ? Given Z for lithium = 3.
(a) 4 (b) 3 (c) 2 (d) 1

17. When the electron in hydrogen atom is excited from the 4th stationary orbit to the 5th stationary orbit, the change in the angular momentum of the electron is (Planck's constant, $h = 6.63 \times 10^{-34}$ J s)
(a) 4.16×10^{-34} J s (b) 3.32×10^{-34} J s
(c) 1.05×10^{-34} J s (d) 2.08×10^{-34} J s

18. The largest wavelength in the ultraviolet region of the hydrogen spectrum is 122 nm. The smallest wavelength in the infrared region of the hydrogen spectrum (to the nearest integer) is
(a) 802 nm (b) 823 nm
(c) 1882 nm (d) 1648 nm

19. When an electron in a hydrogen atom makes a transition from 2nd excited state to ground state it emits a photon of frequency υ. The frequency of photon emitted when an electron of Li^{++} makes a transition from Ist excited state ground state is

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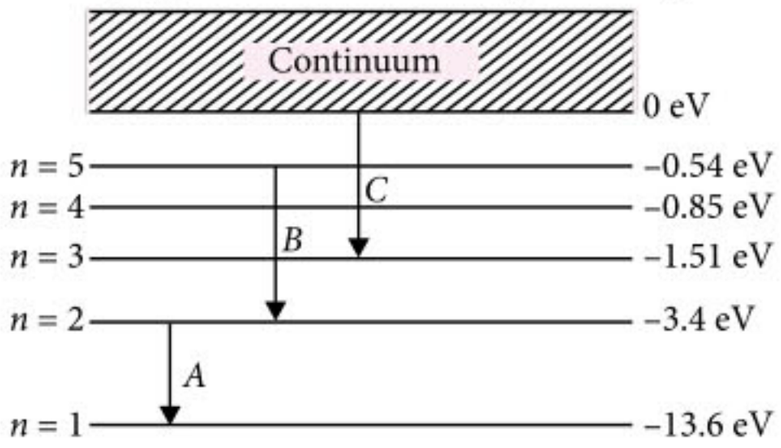
(a) $\frac{243}{32}\upsilon$ (b) $\frac{141}{32}\upsilon$ (c) $\frac{81}{32}\upsilon$ (d) $\frac{63}{32}\upsilon$

20. In Rutherford scattering experiment, the correct angle of scattering of alpha particles for impact parameter equal to zero is
(a) 0° (b) 90° (c) 180° (d) 270°

21. The total energy of an electron in the second excited state of the hydrogen atom is –1.51 eV. The kinetic and potential energies of the electron in this state are respectively
(a) 1.51 eV, –3.02 eV (b) –1.51 eV, 3.02 eV
(c) 3.02 eV, –1.51 eV (d) –3.02 eV, 1.51 eV

22. Figure shows the energy levels of the hydrogen atom along with some transitions marked as *A*, *B* and *C*. The transitions *A*, *B* and *C* respectively represent
(Figure is not drawn upto scale).



(a) the first line of Lyman series, second line of Balmer series and series limit of Paschen series.
(b) the second line of Lyman series, the second line of Balmer series and second line of Paschen series.
(c) the first line of Lyman series, the third line of Balmer series and series limit of Paschen series.
(d) the first line of Lyman series, second line of Balmer series and third line of Paschen series.

23. The angular momentum of an electron in any orbit of hydrogen atom is proportional to (r = radius of the orbit)
(a) $\frac{1}{\sqrt{r}}$ (b) $\frac{1}{r}$ (c) r^2 (d) $\sqrt{r}$

24. The de Broglie wavelength of an electron in 2nd orbit is (a_0 = Bohr radius)
(a) $2\pi a_0$ (b) $4\pi a_0$ (c) $8\pi a_0$ (d) $16\pi a_0$

25. What is the minimum energy that must be given to a H atom in ground state so that it can emit an H_γ line in Balmer series ?
(a) 13.06 eV (b) 12.75 eV
(c) 10.2 eV (d) 2.86 eV

26. The radius of Li^{++} ion in its ground state in terms of Bohr radius a_0 is
(a) a_0 (b) $\frac{a_0}{3}$ (c) $2a_0$ (d) $3a_0$

27. For which of the following atoms/ions Bohr model is not valid?
(a) H (b) He (c) Li^{++} (d) He^{+}

28. Two hydrogen atoms in the ground state collide inelastically. The maximum amount by which their combined kinetic energy is reduced is
(a) 10.2 eV (b) 20.4 eV
(c) 13.6 eV (d) 27.2 eV

29. The ratio of the speed of an electron in the ground state of hydrogen atom to the speed of light in vacuum is
(a) $\frac{1}{137}$ (b) $\frac{2}{137}$ (c) $\frac{1}{237}$ (d) $\frac{2}{237}$

30. The colour of first line of Balmer series is
(a) blue (b) green
(c) violet (d) red

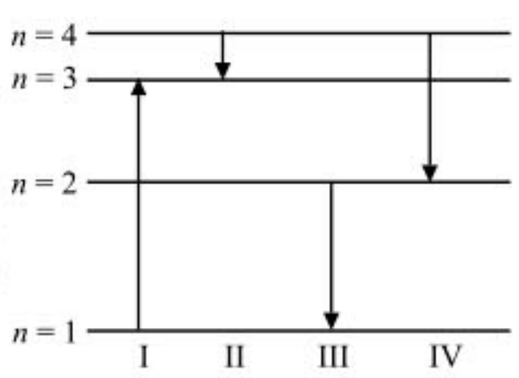
31. Bohr's theory of hydrogen atom is based on the
(a) quantisation of energy
(b) quantisation of charge
(c) quantisation of angular momentum
(d) quantisation of speed

32. An α-particle of energy 5 MeV is scattered through 180° by a gold nucleus. The distance of the closest approach is of the order of
(For gold, $Z = 79$)
(a) 10^{-10} cm (b) 10^{-12} cm
(c) 10^{-14} cm (d) 10^{-16} cm

33. υ_1 is the frequency of the series limit of Lyman series, υ_2 is the frequency of the first line of Lyman series and υ_3 is the frequency of the series limit of the Balmer series. Then
(a) $\upsilon_1 - \upsilon_2 = \upsilon_3$ (b) $\upsilon_1 = \upsilon_2 - \upsilon_3$
(c) $\frac{1}{\upsilon_2} = \frac{1}{\upsilon_1} + \frac{1}{\upsilon_3}$ (d) $\frac{1}{\upsilon_1} = \frac{1}{\upsilon_2} + \frac{1}{\upsilon_3}$

34. The simple Bohr model cannot be directly applied to calculate the energy levels of an atom with many electrons. This is because
(a) of the electrons not being subject to a central force.
(b) of the electrons colliding with each other.
(c) of screening effects.
(d) the force between the nucleus and an electron will no longer be given by Coulomb's law.

35. The diagram shows the energy levels for an electron in a certain atom. Which transition shown represents the emission of a photon with the most energy?



(a) I (b) II (c) III (d) IV

36. In the Bohr model of the hydrogen atom, the lowest orbit corresponds to
(a) zero energy (b) minimum energy
(c) maximum energy (d) infinite energy

37. According to Bohr model of hydrogen atom, the electric current due to motion of electron in n^{th} orbit is proportional to
(a) $\frac{1}{n^3}$ (b) $\frac{1}{n^5}$ (c) n^3 (d) n^5

38. In the Bohr model of hydrogen atom, the ratio of the potential energy to the total energy of an electron in n^{th} state is
(a) –1 (b) 1 (c) –2 (d) 2

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39. A 10 kg satellite circles earth once every 2 h in an orbit having a radius of 8000 km. Assuming that Bohr's angular momentum postulate applies to the satellite, then the quantum number of the orbit of the satellite is (Take $h = 6.6 \times 10^{-34}$ J s)
(a) 5.3×10^{47} (b) 5.3×10^{45}
(c) 5.3×10^{43} (d) 5.3×10^{41}

40. The H_β line of hydrogen
(a) has a wavelength 656.3 nm.
(b) has a wavelength 434.1 nm.
(c) has a wavelength smaller than that of Hγ line.
(d) is emitted in the transition from the third excited state to the first excited state.

41. Which of the following statements is incorrect regarding Rutherford's model of an atom?
(a) Most of the mass of the atom is concentrated at the nucleus.
(b) The size of the nucleus is very large as compared to the size of the atom.
(c) The electrons revolve around the nucleus in well-defined orbits.
(d) None of these

42. Which of the following parameters is the same for all hydrogen-like atoms and ions in their ground states?
(a) Radius of the orbit
(b) Speed of the electron
(c) Energy of the atom
(d) Orbital angular momentum of the electron

43. What is the wavelength of light for the least energetic photon emitted in the Lyman series of the hydrogen atom spectrum?
(Take $hc = 1240$ eV nm)
(a) 82 nm (b) 102 nm (c) 122 nm (d) 150 nm

44. The energy of an excited hydrogen atom is –3.4 eV. The angular momentum of the electron is
(Take $h = 6.63 \times 10^{-34}$ J s)
(a) 1.05×10^{-34} J s (b) 2.11×10^{-34} J s
(c) 3.16×10^{-34} J s (d) 4.22×10^{-34} J s

45. The radius of the orbit of an electron in a hydrogen-like atom (atomic number Z) is $4.5a_0$ where a_0 is the Bohr radius. Its orbital angular momentum is $\frac{3h}{2\pi}$. The value of Z is
(a) 2 (b) 3 (c) 4 (d) 5

DAY 26 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ◉

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____
(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (c) : Energy of an electron in the n^{th} orbit of the hydrogen atom is

$$E_n = -\frac{13.6}{n^2}\text{eV}$$

Energy of electron in second orbit is

$$E_2 = -\frac{13.6}{2^2}\text{eV} \quad = -\frac{13.6}{4}\text{eV} = -3.4\text{ eV}$$

Energy required to remove an electron from second orbit is

$E = E_\infty - E_2$

$E = 0 - (-3.4)$ eV or $E = 3.4$ eV

Hence, the required energy is 3.4 eV.

2. (d): The wavelength of the first line of lyman series for hydrogen atom is

$$\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{2^2}\right]$$

The wavelength of the second line of Balmer series for hydrogen like ion is

$$\frac{1}{\lambda'} = Z^2R\left[\frac{1}{2^2} - \frac{1}{4^2}\right]$$

According to question, $\lambda = \lambda'$

$$\Rightarrow \quad R\left[\frac{1}{1^2} - \frac{1}{2^2}\right] = Z^2R\left[\frac{1}{2^2} - \frac{1}{4^2}\right]$$

or $\quad \frac{3}{4} = \frac{3Z^2}{16} \quad$ or $\; Z^2 = 4 \;$ or $\; Z = 2$

3. (d): Helium atom has 2 electrons. When one electron is removed, the remaining atom is hydrogen like atom, whose energy in first orbit is

$E_1 = -(2)^2(13.6\text{ eV}) = -54.4$ eV

Therefore, to remove the second electron from the atom, an additional energy of 54.4 eV is required. Hence, total energy required to remove both the electrons = 24.6 + 54.4 = 79.0 eV.

4. (d): In the first case, energy emitted, $E_1 = 2E - E = E$

In the second case, energy emitted

$$E_2 = \frac{4E}{3} - E = \frac{E}{3}$$

As E_2 is $\left(\frac{1}{3}\right)^{\text{rd}}$, λ_2 must be 3 times, *i.e.* 3λ.

5. (b): $E^H = 13.6$ eV,

First excited state of $Li^{++}(Z = 3)$ corresponds to $n = 2$.

$$E_{n_{(Li^{++})}} = \frac{E_H Z^2}{n^2} = \frac{13.6 \times (3)^2}{(2)^2} = 30.6\text{ eV}$$

6. (d): According to Rydberg's formula

$$\frac{1}{\lambda} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

For Lyman series, $n_1 = 1$ and $n_2 = 2$ for first line

$$\therefore \quad \frac{1}{\lambda_1} = R\left[\frac{1}{1^2} - \frac{1}{2^2}\right] = R\left[\frac{1}{1} - \frac{1}{4}\right] = \frac{3}{4}R$$

For Paschen series, $n_1 = 3$ and $n_2 = 4$ for first line

$$\therefore \quad \frac{1}{\lambda_2} = R\left[\frac{1}{3^2} - \frac{1}{4^2}\right] = R\left[\frac{1}{9} - \frac{1}{16}\right] = \frac{7}{144}R$$

$$\frac{\lambda_1}{\lambda_2} = \frac{\frac{4}{3}R}{\frac{144}{7}R} = \frac{7}{108}$$

7. (d): For hydrogen like ions

$$E_n = -\frac{13.6(Z^2)}{n^2}\text{ eV}$$

When $n = 1$, $\quad E_1 = -13.6(Z^2)$ eV

When $n = \infty$, $\quad E_\infty = 0$

Ionisation energy for the last electron = $E_\infty - E_1$

$= 0 - [-(13.6)(11)^2] = 13.6 \times (11)^2$ eV

8. (b)

9. (a) : According to Bohr theory of hydrogen atom

$r \propto n^2$

$v \propto \frac{1}{n}$

$E \propto \frac{1}{n^2} \quad \therefore \quad vr \propto n$

10. (c) : In Bohr model of hydrogen atom, the period of revolution of electron in n^{th} orbit is given as $T_n = \frac{4\varepsilon_0^2 h^3 n^3}{me^4}$

$T_n \propto n^3$

$$\therefore \quad \frac{T_2}{T_1} = \left(\frac{2}{1}\right)^3 = \frac{8}{1}$$

11. (b): In second excited state, $n = 3$,

So, $l_H = l_{Li} = 3\left(\frac{h}{2\pi}\right)$

while $E \propto Z^2$ and $Z_H = 1$, $Z_{Li} = 3$

So, $|E_{Li}| = 9|E_H|$ or $|E_H| < |E_{Li}|$

12. (a) : For Brackett series, $\frac{1}{\lambda} = R\left[\frac{1}{4^2} - \frac{1}{n^2}\right]$

where $n = 5, 6, 7, 8, \ldots\ldots$

For longest wavelength, $n = 5$

$$\therefore \quad \frac{1}{\lambda_{\text{Longest}}} = R\left[\frac{1}{4^2} - \frac{1}{5^2}\right] = R\left[\frac{1}{16} - \frac{1}{25}\right] = \frac{9}{400}R \qquad \ldots(i)$$

For shortest wavelength, $n = \infty$

$$\therefore \quad \frac{1}{\lambda_{\text{Shortest}}} = R\left[\frac{1}{4^2} - \frac{1}{\infty^2}\right] = \frac{R}{16} \qquad \ldots(ii)$$

Dividing (ii) by (i), we get

$$\frac{\lambda_{\text{Longest}}}{\lambda_{\text{Shortest}}} = \frac{R}{16} \times \frac{400}{9R} = \frac{25}{9}$$

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13. (a) : Given : $V = V_0 \ln\left(\frac{r}{r_0}\right)$

$\therefore$ Potential energy, $U = eV$

or $U = eV_0 \ln\left(\frac{r}{r_0}\right)$ $\therefore$ $\frac{dU}{dr} = eV_0\left(\frac{r_0}{r}\right)\frac{1}{r_0}$

Force, $F = -\frac{dU}{dr} = -\frac{eV_0}{r}$ or $|F| = \frac{eV_0}{r}$

This force provides the necessary centripetal force.

$\therefore$ $\frac{mv^2}{r} = \frac{eV_0}{r}$ or $v = \sqrt{\frac{eV_0}{m}}$ ...(i)

By Bohr's postulate, $mvr = \frac{nh}{2\pi}$ or $v = \frac{nh}{2\pi mr}$ ...(ii)

From equations (i) and (ii), we get

$\frac{nh}{2\pi mr} = \sqrt{\frac{eV_0}{m}}$ or $r = \frac{nh}{2\pi m} \times \sqrt{\frac{m}{eV_0}}$

or $r = \left[\frac{h}{2\pi}\sqrt{\frac{1}{meV_0}}\right] \times n$

$\therefore r_n \propto n$

14. (a) : Number of spectral lines emitted is $N = \frac{n(n-1)}{2}$

Here $n = 9$ $\therefore$ $N = \frac{9(9-1)}{2} = \frac{9\times 8}{2} = 36$

15. (b) : $a_0 = \frac{h^2\varepsilon_0}{\pi m e^2}$ ...(i)

$a_\mu = \frac{h^2\varepsilon_0}{\pi(207m)e^2}$ ...(ii)

Dividing (ii) by (i), we get, $\frac{a_\mu}{a_0} = \frac{1}{207}$ or $a_\mu = \frac{a_0}{207}$

16. (b): The energy of n^{th} state of a hydrogen like atom is given as

$E_n = \frac{CZ^2}{n^2}$, where C is a constant.

For ground state of hydrogen atom, $Z = 1$, $n = 1$

$\therefore$ $E_1 = \frac{C(1)^2}{(1)^2} = C$

For n^{th} state of Li^{2+} ion $(Z = 3)$; $E_n = \frac{C(3)^2}{n^2} = \frac{9C}{n^2}$

As $E_n = E_1$ $\therefore$ $\frac{9C}{n^2} = C$ or $n^2 = 9$ or $n = 3$

17. (c) : According to Bohr's quantisation condition

$L_n = \frac{nh}{2\pi}$

$\therefore$ For $n = 4$, $L_4 = \frac{4h}{2\pi}$

and for $n = 5$, $L_5 = \frac{5h}{2\pi}$

$\therefore$ Change in angular momentum when an electron is excited from $n = 4$ to $n = 5$ is

$\Delta L = L_5 - L_4 = \frac{5h}{2\pi} - \frac{4h}{2\pi} = \frac{h}{2\pi} = \frac{6.63\times 10^{-34}}{2\times 3.14}$ J s $= 1.05 \times 10^{-34}$ J s

18. (b): The smallest frequency and largest wavelength in ultraviolet region will be for transition from $n_2 = 2$ to $n_1 = 1$

$\therefore$ $\frac{1}{\lambda_{max}} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$

$\Rightarrow$ $\frac{1}{\lambda_{max}} = R\left[\frac{1}{1^2} - \frac{1}{2^2}\right] = R\left[1 - \frac{1}{4}\right] = \frac{3R}{4}$ ...(i)

The highest frequency and smallest wavelength for infrared region will be for transition from $n_2 = \infty$ to $n_1 = 3$

$\therefore$ $\frac{1}{\lambda_{min}} = R\left(\frac{1}{3^2} - \frac{1}{\infty}\right) = \frac{R}{9}$ ...(ii)

Divide (i) by (ii), we get

$\frac{\lambda_{min}}{\lambda_{max}} = \frac{3R}{4} \times \frac{9}{R} = \frac{27}{4}$

$\lambda_{min} = \frac{27}{4} \times \lambda_{max} = \frac{27}{4} \times 122$ nm $= 823.5$ nm

19. (a)

20. (c) : For angle of scattering, $\theta = 180°$, the impact parameter is zero.

21. (a) : In the second excited state,

Total energy, $E = -1.51$ eV

Kinetic energy, $K = -E = -(-1.51\text{ eV}) = 1.51$ eV

Potential energy, $U = 2E = 2(-1.51\text{ eV}) = -3.02$ eV

22. (c) : A represents the first line of Lyman series, B represents the third line of Balmer series and C represents series limit of Paschen series.

23. (d): According to Bohr's quantisation condition

Angular momentum, $L = \frac{nh}{2\pi}$

As $r \propto n^2$, Hence, $L \propto \sqrt{r}$.

24. (b): Radius of n^{th} orbit is

$r_n = n^2 a_0$ where a_0 is, the Bohr radius.

If λ is the de Broglie wavelength of an electron while revolving in n^{th} orbit of radius r_n, then

$2\pi r_n = n\lambda$; $\lambda = \frac{2\pi r_n}{n}$

For 2^{nd} orbit, $n = 2$

$\therefore$ $\lambda = \frac{2\pi r_2}{2} = \frac{2\pi(2)^2 a_0}{2} = 4\pi a_0$

25. (a) : H_γ line in the Balmer series corresponds to transition from $n = 5$ to $n = 2$.

Therefore, electron in the ground state (n = 1) must be raised first to the state ($n = 5$).

The minimum energy required for this purpose is

$E = E_5 - E_1$

$= -\frac{13.6}{5^2}\text{eV} - \left(-\frac{13.6}{1^2}\text{eV}\right)$ $\left(\text{As } E_n = -\frac{13.6}{n^2}\text{eV}\right)$

$= -0.54\text{ eV} + 13.6\text{ eV} = 13.06$ eV

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26. (b): Radius of n^{th} orbit of hydrogen-like atom is

$$r_n = \frac{n^2}{Z} a_0$$

For Li^{++} ion, $Z = 3$, $n = 1$ for ground state

$\therefore$ Radius of Li^{++} ion in its ground state is

$$r_1 = \frac{(1)^2}{3} a_0 = \frac{a_0}{3}$$

27. (b): Bohr model is valid only for one-electron atoms/ions.

Bohr model is not valid in He atom because it has two electrons.

28. (a): Initial kinetic energy of each of two hydrogen atoms in ground state = 13.6 eV

$\therefore$ Kinetic energy of both H atoms before collision $= 2 \times 13.6$ eV$= 27.2$ eV

As the collision is inelastic, linear momentum is conserved but some kinetic energy is lost.

If one H atom goes to first excited state and other remains in ground state, then their combined kinetic energy after collision

$$= \frac{13.6}{2^2} \text{ eV} + 13.6 \text{ eV} = 17 \text{ eV}$$

$\therefore$ Reduction in their combined kinetic energy

$= 27.2 \text{ eV} - 17 \text{ eV} = 10.2 \text{ eV}$

29. (a): Speed of an electron in the ground state of hydrogen atom is

$$v = \frac{1}{4\pi\varepsilon_0}\frac{2\pi e^2}{h} = c\left(\frac{1}{4\pi\varepsilon_0}\frac{2\pi e^2}{ch}\right) = \alpha c = \frac{c}{137}$$

where c = speed of light in vacuum

$$\alpha = \frac{1}{4\pi\varepsilon_0}\frac{2\pi e^2}{ch} = \frac{1}{137} = \text{Fine structure constant}$$

$$\therefore \quad \frac{v}{c} = \frac{1}{137}$$

30. (d): The colour of first line of Balmer series is red.

31. (c): Bohr's theory of hydrogen atom is based on quantisation of angular momentum.

32. (b): At the distance of closest approach d,

Kinetic energy of an alpha particle

= Potential energy of alpha particle and the gold nucleus.

$$K = \frac{1}{4\pi\varepsilon_0}\frac{(2e)(Ze)}{d}; \quad d = \frac{1}{4\pi\varepsilon_0}\frac{2Ze^2}{K}$$

Here, $K = 5$ MeV $= 5 \times 10^6$ eV $= 5 \times 10^6 \times 1.6 \times 10^{-19}$ J

$= 5 \times 1.6 \times 10^{-13}$ J

$Z = 79$

$$\therefore \quad d = \frac{9\times10^9 \times 2 \times 79 \times (1.6\times10^{-19})^2}{5\times1.6\times10^{-13}}$$

$= 4.55 \times 10^{-14}$ m $\sim 10^{-12}$ cm

33. (a): For Lyman series

$$\upsilon = Rc\left[\frac{1}{1^2} - \frac{1}{n^2}\right] \text{ where } n = 2, 3, 4, \ldots$$

For the series limit of Lyman series, $n = \infty$

$$\therefore \quad \upsilon_1 = Rc\left[\frac{1}{1^2} - \frac{1}{\infty^2}\right] = Rc \qquad \ldots(i)$$

For the first line of Lyman series, $n = 2$

$$\therefore \quad \upsilon_2 = Rc\left[\frac{1}{1^2} - \frac{1}{2^2}\right] = \frac{3}{4}Rc \qquad \ldots(ii)$$

For Balmer series

$$\upsilon = Rc\left[\frac{1}{2^2} - \frac{1}{n^2}\right] \text{ where } n = 3, 4, 5....$$

For the series limit of Balmer series, $n = \infty$

$$\therefore \quad \upsilon_3 = Rc\left[\frac{1}{2^2} - \frac{1}{\infty^2}\right] = \frac{Rc}{4} \qquad \ldots(iii)$$

From equations (i), (ii) and (iii), we get

$\upsilon_1 = \upsilon_2 + \upsilon_3$ or $\upsilon_1 - \upsilon_2 = \upsilon_3$

34. (a): Each electron interacts not only with the positively charged nucleus (which provides the central force) but also with all other electrons *i.e.* we have to take into account electron-electron interaction. Thus, the electrons are not being subjected to a central force.

35. (c): Ist transition is showing absorption of a photon. From rest of three transitions, III is having maximum energy from level $n = 2$ to $n = 1$

$$\Delta E \propto \left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

36. (b): In hydrogen atom, the lowest orbit corresponds to minimum energy.

37. (a): Electric current due to motion of electron in n^{th} orbit is, $I_n = e\upsilon_n$

For hydrogen atom,

Frequency of electron in n^{th} orbit is

$$\upsilon_n = \left(\frac{1}{4\pi\varepsilon_0}\right)^2 \frac{4\pi^2 e^4 m}{n^3 h^3} \qquad \ldots(i)$$

$$\therefore \quad I_n = \left(\frac{1}{4\pi\varepsilon_0}\right)^2 \frac{4\pi^2 e^5 m}{n^3 h^3} \quad \text{(Using(i))}$$

Thus, $I_n \propto \frac{1}{n^3}$

38. (d): For hydrogen atom,

The kinetic energy of the electron in n^{th} state is

$$K = \frac{me^4}{8\varepsilon_0^2 h^2 n^2} = \frac{13.6}{n^2} \text{ eV}$$

where $\frac{me^4}{8\varepsilon_0^2 h^2} = 13.6$ eV

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The potential energy of the electron in n^{th} state is

$$U = -\frac{2me^4}{8\varepsilon_0^2 h^2 n^2} = -\frac{27.2}{n^2} \text{ eV}$$

Total energy of the electron in n^{th} state is

$$E = K + U = \frac{me^4}{8\varepsilon_0^2 h^2 n^2} - \frac{2me^4}{8\varepsilon_0^2 h^2 n^2}$$

$$= -\frac{me^4}{8\varepsilon_0^2 h^2 n^2} = -\frac{13.6}{n^2} \text{ eV} \quad \therefore \quad \frac{U}{E} = 2$$

39. (b): Here, $m = 10$ kg,

$r = 8000 \text{ km} = 8000 \times 10^3 \text{ m} = 8 \times 10^6 \text{ m}$,

$T = 2 \text{ h} = 7200 \text{ s}$

According to Bohr's second postulate

$$L = mvr = \frac{nh}{2\pi}; \quad \text{As } v = \frac{2\pi r}{T}$$

$$\therefore \quad m\left(\frac{2\pi r}{T}\right) r = \frac{nh}{2\pi}$$

$$n = \frac{(2\pi r)^2 m}{Th} = \frac{(2 \times 3.14 \times 8 \times 10^6)^2 \times 10}{7200 \times 6.6 \times 10^{-34}} = 5.3 \times 10^{45}$$

40. (d): The wavelength of Hβ line is 486.1 nm.

The wavelength of H_β line is greater than that of H_γ line ($\lambda_{H_\gamma} = 434.1$ nm).

H_β line corresponds to transition from the third excited state ($n = 4$) to the first excited state ($n = 2$).

41. (b): The size of the nucleus ($\approx 10^{-15}$ m) is very small as compared to the size of the atom ($\approx 10^{-10}$ m).

42. (d)

43. (c) : For any series, the transition that produces the least energetic photon is the transition between the home-base level that defines the series and the level immediately above it.

For the Lyman series, the home-base level is at $n = 1$. Thus, the transition that produces the least energetic photon is the transition from the $n = 2$ level to the $n = 1$ level.

As $E_n = -\frac{13.6}{n^2}$ eV

$$\therefore \quad E_1 = -\frac{13.6}{1^2} \text{ eV} = -13.6 \text{ eV}$$

and $E_2 = -\frac{13.6}{2^2} \text{ eV} = -3.4 \text{ eV}$

The corresponding energy difference is

$$\Delta E = E_2 - E_1 = -3.4 \text{ eV} - (-13.6 \text{ eV}) = 10.2 \text{ eV}$$

Wavelength of emitted photon is

$$\lambda = \frac{hc}{\Delta E} = \frac{1240 \text{ eV nm}}{10.2 \text{ eV}} = 122 \text{ nm}$$

44. (b): The energy of n^{th} state of hydrogen atom is

$$E_n = -\frac{13.6}{n^2} \text{ eV}$$

$$\therefore \quad n^2 = \frac{-13.6 \text{ eV}}{E_n} = \frac{-13.6 \text{ eV}}{-3.4 \text{ eV}} = 4 \quad (\because E_n = -3.4 \text{ eV})$$

$$\therefore \quad n = 2$$

According to Bohr's quantisation condition

Angular momentum, $L = \frac{nh}{2\pi} = \frac{2h}{2\pi} = \frac{h}{\pi} = \frac{6.63 \times 10^{-34} \text{ J s}}{3.14}$

$= 2.11 \times 10^{-34}$ J s

45. (a) : According to Bohr's quantisation condition

$$L = \frac{nh}{2\pi}$$

Given : $L = \frac{3h}{2\pi} \quad \therefore \quad \frac{3h}{2\pi} = \frac{nh}{2\pi}$ or $n = 3$

Radius of n^{th} orbit for hydrogen-like atom is $r_n = \frac{n^2}{Z} a_0$

where a_0 is the Bohr radius

Here, $r_n = 4.5a_0$

$$\therefore \quad 4.5a_0 = \frac{(3)^2}{Z} a_0 \text{ or } Z = \frac{9}{4.5} = 2$$

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Nuclei

Nucleus

The nucleus is a positively charged core located at the centre of the atom. Almost the entire mass of the atom is concentrated in its nucleus.

Composition of the nucleus

The nucleus of an atom contains protons and neutrons which are collectively known as nucleons. The number of protons in a nucleus is called its atomic number and is denoted by Z. The total number of protons and neutrons in a nucleus is called its mass number and is denoted by A.

Number of protons in an atom = Z

Number of electrons in an atom = Z

Number of nucleons in an atom = A

Number of neutrons in an atom = $N = A - Z$

- Isotopes : Nuclei having same atomic number but different mass numbers are called isotopes.
  e.g., ${}^{2}_{1}\mathrm{H}$, ${}^{3}_{1}\mathrm{H}$
- Isobars: Nuclei having same mass number but different atomic numbers are called isobars.
  e.g., ${}^{14}_{6}\mathrm{C}$, ${}^{14}_{7}\mathrm{N}$.
- Isotones : Nuclei having same number of neutrons, but different atomic number and mass number are called isotones.
  e.g., ${}^{3}_{1}\mathrm{H}$, ${}^{4}_{2}\mathrm{He}$.

Size of the nucleus

The nuclear density of nuclear matter is approximately constant. This implies that the number of nucleons within a nucleus (mass number A) is proportional to its volume.

$$A \propto \left(\frac{4}{3}\pi R^3\right)$$

The size of the nucleus depends on the number of nucleons present in it.

The statistical radius of a nucleus is therefore given by

$$R = R_0 A^{1/3}$$

Where,

$$R_0 = 1.1 \times 10^{-15}\ \mathrm{m}$$

A = mass number of the nucleus

Nuclear Force

In a nucleus, protons are held together in small volume and hence they are acted upon by large electrostatic repulsive forces. The nucleons within a nucleus are held together due to an attractive nuclear force. It is an attractive force irrespective of the nature of charge on the particles. This force comes into play when distance between nucleons is of the order of 10^{-14} m. At these distance, the nuclear force is 50 to 60 times greater than electrostatic forces.

Mass Defect

The actual mass of a nucleus is experimentally observed to be smaller than the sum of the masses of free nucleons constituting it. The difference between the experimental mass, $m({}_{z}X^{A})$ of a nucleus and the sum of the masses of free nucleons (Z protons, and $A - Z$ neutrons) is known as the mass defect.

$$\Delta m = Zm_p + (A - Z)m_n - m({}_{z}X^{A})$$

Binding Energy

The amount of energy needed to disintegrate a nucleus into its constituent nucleons is called binding energy. It is the energy equivalent to the mass defect

$$\mathrm{B.E} = \Delta m c^2, \text{ where } c = \text{velocity of light}$$

If mass is measured in amu then B.E. = $\Delta m \times 931.5$ MeV

As 1 amu = 931 MeV

Radioactivity

Radioactivity is the spontaneous disintegration of nuclei of some nuclides (called radionuclides) with the emission of alpha particles or beta particles, some accompanied by a gamma ray emission.

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Comparison of α, β and γ rays			
	α-particle/ray	**β-particle/ray**	**γ-ray**
Charge and Mass	2 unit (+ve); 4 unit mass	1 unit (–ve); same that of electron	Electromagnetic rays, with very short wavelength
Nature	Fast moving ^4_2He or He^{++}	Fast moving $_{-1}e^0$	$_0\gamma^0$
Velocity	1/10th of light	33% to 90% of light	Same as light
Electric field	Deflected towards the cathode	Deflected towards the anode	Not deflected
Penetrating power	Low, or (0.01 mm of Al foil)	100 times of α-particle	100 times of β-particle
Relative ionizing power	Very high, nearly 100 times of β-rays	Low, nearly 100 times of γ-rays	Very low
Nature of product	Product obtained by the loss of one α-particle has atomic number less by 2 units and mass number by 4 units.	Product obtained by the loss of one β-particle has atomic number more by 1 unit, without any change in mass number.	There is no change in atomic number as well as mass number.

Law of radioactive decay

$$\frac{dN}{dt} = -\lambda N(t) \quad \text{or} \quad N(t) = N_0 e^{-\lambda t}$$

where λ is the probability per unit time for a nucleus to decay and N(t) is the number of radioactive nuclei present at time t.

- Half-life of a radioactive substance is given by

$$T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$$

- Mean-life or average life of a radioactive substance is given by

$$\tau = \frac{1}{\lambda} = \frac{T_{1/2}}{0.693} = 1.44 T_{1/2}$$

- Activity is the number of disintegrations occurring in a radioactive substance per second and it is given by

$$R = -\frac{dN}{dt}.$$

The S.I. unit of activity is becquerel.

1 becquerel = 1 Bq = 1 decay/second

The traditional unit of activity is the curie.

1 curie = 1 Ci = 3.70×10^{10} decays/s = 37 GBq.

The other unit of radioactivity is rutherford.

1 rutherford = 10^6 disintegrations/s.

Activity law $R(t) = R_0 e^{-\lambda t}$

where $R_0 = \lambda N_0$ is the decay rate at $t = 0$ and $R = N\lambda$.

Alpha decay

A nucleus that decays spontaneously by emitting an alpha particle (a helium nucleus ^4_2He) is said to undergo alpha decay. The alpha decay is represented by

$$^A_Z X \rightarrow {}^{A-4}_{Z-2}Y + {}^4_2He$$

where $^A_Z X$ is the parent nucleus and $^{A-4}_{Z-2}Y$ is the daughter nucleus.

In an alpha decay disintegration energy Q is given by

$$Q = (m_X - m_Y - m_{He})c^2$$

Kinetic energy of alpha particles is given by

$$KE_\alpha = \frac{A-4}{A} Q$$

where A is the mass number of parent nucleus.

Beta decay

A nucleus that decays spontaneously by emitting an electron or a positron is said to undergo beta decay.

In beta minus decay (β^-), a neutron is transformed into a proton and an electron and antineutrino is emitted.

$$n \rightarrow p + e^- + \bar{\nu}$$

where n is the neutron, p is the proton, e^- is the electron and $\bar{\nu}$ is the antineutrino.

The beta minus decay is represented by

$$^A_Z X \rightarrow {}^A_{Z+1}Y + e^- + \bar{\nu}$$

In beta minus decay, disintegration energy Q is given by

$$Q = [m_X - m_Y]c^2$$

In beta plus decay (β^+) or positron emission, a proton is transformed into neutron and positron and neutrino is emitted.

$$p \rightarrow n + e^+ + \nu$$

wehre e^+ is the positron and ν is the neutrino.

The beta plus decay is represented by

$$^A_Z X \rightarrow {}^A_{Z-1}Y + e^+ + \nu$$

In beta plus decay, the disintegration energy is given by

$$Q = [mX - mY - 2m_e]c^2$$

where m_e is the mass of the electron.

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The kinetic energy of an electron or a positron in the beta decay vary continuously from zero to a certain maximum value $K.E_{max}$. The maximum kinetic energy $K.E_{max}$ of an electron or positron must equal the disintegration energy Q.

Gamma decay

When a nucleus in an excited state makes a transition to state of lower energy, electromagnetic radiation of very short wavelength is emitted.

The gamma decay is represented by

$$^{A}_{Z}X^{*} \rightarrow {}^{A}_{Z}X + \gamma$$

* denotes the excited nuclear state.

Nuclear Reaction

A nuclear reaction is represented by

$$A + a \rightarrow B + b + Q$$

where A is the target nucleus, a is the impinging particle, B and b the products, Q is the energy released in the process.

The nuclear reaction is represented by notation $A(a, b)B$.

Q value of nuclear reaction,

$$Q = (m_A + m_a - m_B - m_b)c^2$$

If Q is positive, the reaction is exothermic and if Q is negative the reaction is endothermic.

Nuclear fission

A heavy unstable nucleus breaks into two or more smaller parts. An energy of about 200 MeV is released and 3 neutrons are emitted when $^{92}_{235}U$ splits by the impact of a slow neutron.

$$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{236}_{92}U \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3(^{1}_{0}n) + 200 \text{ MeV}$$

Atom bomb is based on nuclear fission.

About 99.9% of energy is converted into heat. Rest is converted into kinetic energy of neutrons, γ-rays, light and product nuclei.

Nuclear reactor : It is the furnace in which energy is generated by controlled nuclear fission.

- Fuel : The material like $^{235}_{92}U$, $^{238}_{92}U$, $^{239}_{94}Pu$ which can undergo fission by a neutron is known as fuel.
- Moderator : The material like heavy water, graphite and beryllium oxide which can retard and control the fast moving neutrons is called moderator.
- Coolant : The material like cold water, cold air current, heavy water, liquid oxygen which can absorb the heat generated is known as coolant.
- Control rods : The rods of material like cadmium, which can control the rate of chain reaction by absorbing extra neutrons are called control rods.
- **Controlled chain reaction** is slow and needs only one neutron for further fission, on which control is possible. Atomic reactors work on the basis of controlled chain reaction.
- **Uncontrolled chain reaction** is fast and needs more than one neutron for further fission. Atom bomb is an example. It cannot be controlled once the fission starts.

Nuclear fusion

Two or more than two lighter nuclei combine to form a heavy nucleus with liberation of energy constitute nuclear fusion.

$$4(^{1}_{1}H) + 4\ {}^{0}_{-1}e \rightarrow {}^{4}_{2}He + 2(\ {}^{0}_{-1}e) + 2\upsilon + 27 \text{ MeV}$$

Temperature should be high about 10^7 K.

Pressure should be large about 10^6 atmosphere.

The kinetic energy of interacting nuclei must be greater than the Coulomb repulsive energy *i.e.* about 0.1 MeV.

Hydrogen bomb is based on fusion.

Thermonuclear energy : The energy released during nuclear fusion is known as thermonuclear energy.

Protons are needed for fusion while neutrons are needed for fission process.

Fusion reactors are better than fission reactors because harmful radiations are not produced in them.

- **Proton-proton cycle :** This cycle is the source of energy in the Sun.

$$4(^{1}_{1}H) + 4\ {}^{0}_{-1}e \rightarrow {}^{4}_{2}He + 2(\ {}^{0}_{-1}e) + 2\upsilon + 27 \text{ MeV}$$

  Temperature in Sun = 1.5×10^7 K
- **Carbon-nitrogen cycle :** This cycle occurs in stars bigger than sun at temperature = 2×10^7 K.

Carbon Dating

Carbon dating is used to find the age of archeological samples and the plant etc. All the live plants and bones of animals have C^{14} which is in equilibrium with C^{14} in the atmosphere and remain constant as long as plant or animal is alive, but after the same dies, radio carbon C^{14} continues to disintegrate and the number of disintegrations per second decreases with time. Thus the time taken by C^{14} to decay when the plant or animal died and ceased to assimilate C^{14} can be easily estimated.

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EXAM DRILL

1. A triton contains
(a) 1 proton + 2 neutrons
(b) 1 proton + 1 neutron
(c) 2 protons + 1 neutron
(d) 2 protons + 2 neutrons

2. There are two radioactive substances A and B. Decay constant of B is two times that of A. Initially, both have equal number of nuclei. After n half lives of A, rate of disintegration of both are equal. The value of n is
(a) 4 (b) 2 (c) 1 (d) 5

3. If a star converts all helium in its core to oxygen then energy released per oxygen nucleus is
(Mass of He = 4.0026 u, Mass of O = 15.9994 u)
(a) 10.24 MeV (b) 5 MeV
(c) 7.56 MeV (d) 23.9 MeV

4. A sample of radioactive element has a mass of 10 g at an instant $t = 0$. The approximate mass of this element in the sample, after two mean lives, is
(a) 2.50 g (b) 3.70 g
(c) 6.30 g (d) 1.35 g

5. After 280 days, the activity of a radioactive sample is 6000 dps. The activity reduces to 3000 dps after another 140 days. The initial activity of the sample in dps is
(a) 6000 (b) 9000
(c) 3000 (d) 24000

6. The half life of radioactive radon is 3.8 days. The time at the end of which $\left(\frac{1}{20}\right)^{th}$ of the radon sample will remain undecayed is
(a) 3.8 days (b) 16.5 days
(c) 33 days (d) 76 days

7. A fraction f_1 of a radioactive sample decays in one mean life, and a fraction f_2 decays in one half life. Then
(a) $f_1 > f_2$
(b) $f_1 < f_2$
(c) $f_1 = f_2$
(d) May be (a), (b) or (c) depending on the values of the mean life and half life.

8. In a sample of radioactive material, what fraction of the initial number of active nuclei will remain undisintegrated after half of a half life of the sample?
(a) $\frac{1}{4}$ (b) $\frac{1}{2\sqrt{2}}$ (c) $\frac{1}{\sqrt{2}}$ (d) $\sqrt{2}-1$

9. The mass of deuteron ($_1H^2$) nucleus is 2.014102 u. If the masses of proton and neutron are 1.007825 u and 1.008665 u respectively, then the binding energy per nucleon of $_1H^2$ nucleus is
(a) 2.2 MeV (b) 1.1 MeV
(c) 0.5 MeV (d) 0.25 MeV

10. A radioactive substance with decay constant of 0.5 s^{-1} is being produced at a constant rate of 50 nuclei per second. If there are no nuclei present initially, the time (in second) after which 25 nuclei will be present is
(a) 1 (b) $2\ln\left(\frac{4}{3}\right)$ (c) $\ln 2$ (d) $\ln\left(\frac{4}{3}\right)$

11. Two radioactive sources A and B of half lives 1 h and 2 h respectively initially contain the same number of radioactive atoms. At the end of two hours, their rates of disintegration are in the ratio of
(a) 1 : 4 (b) 1 : 3 (c) 1 : 2 (d) 1 : 1

12. A radioactive nucleus undergoes a series of decay according to the scheme

$$A \xrightarrow{\alpha} A_1 \xrightarrow{\beta} A_2 \xrightarrow{\alpha} A_3 \xrightarrow{\gamma} A_4$$

If the mass number and atomic number of A are 180 and 72 respectively, these numbers of A_4 are
(a) 172, 69 (b) 177, 69
(c) 171, 69 (d) 172, 68

13. A radioactive element X with half life 2 h decays giving a stable element Y. After a time t, ratio of X and Y atoms is 1 : 16. Time t is
(a) 6 h (b) 4 h (c) 8 h (d) 16 h

14. Li nucleus has three protons and four neutrons. Mass of Li nucleus is 7.016005 amu, mass of proton is 1.007277 amu and mass of neutron is 1.008665 amu. Mass defect of lithium nucleus in amu is
(a) 0.04048 amu (b) 0.04050 amu
(c) 0.04052 amu (d) 0.04055 amu

15. Two radioactive substances A and B have decay constant 5λ and λ respectively. At $t = 0$, they have the same number of nuclei. The ratio of number of nuclei of A to that of B will be $(1/e)^2$ after a time interval of
(a) $\frac{1}{\lambda}$ (b) $\frac{1}{2\lambda}$ (c) $\frac{1}{3\lambda}$ (d) $\frac{1}{4\lambda}$

16. The half life of a radioactive nucleus is 50 days. The time interval $(t_2 - t_1)$ between the time t_2 when $\frac{2}{3}$ of it has decayed and the time t_1 when $\frac{1}{3}$ of it had decayed is
(a) 30 days (b) 50 days
(c) 60 days (d) 15 days

17. A radioactive substance decays at the rate of 5000 disintegration per minute. After 5 minutes it disintegrates at 1250 disintegration per minute. The decay constant is
(a) $0.2\ln 2\ min^{-1}$ (b) $0.4\ln 2\ min^{-1}$
(c) $0.6\ln 2\ min^{-1}$ (d) $0.8\ln 2\ min^{-1}$

18. The energy released in the fission of 1 kg of $_{92}U^{235}$ is
(Energy per fission = 200 MeV)
(a) 5.1×10^{26} eV (b) 5.1×10^{26} J
(c) 8.2×10^{13} J (d) 8.2×10^{13} MeV

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19. The radioactivity of a sample is X at a time t_1 and Y at a time t_2. If the mean life time of the specimen is τ, the number of atoms that have disintegrated in the time interval $(t_1 - t_2)$ is

(a) $Xt_1 - Yt_2$ (b) $X - Y$ (c) $\frac{X-Y}{\tau}$ (d) $(X-Y)\tau$

20. In the following reaction, the energy released is

$4\,{}_1^1H \rightarrow {}_2^4He + 2e^+ + \text{Energy}$

Given :

Mass of ${}_1^1H = 1.007825$ u

Mass of ${}_2^4He = 4.002603$ u

Mass of $e^+ = 0.000548$ u

(a) 12.33 MeV (b) 24.67 MeV
(c) 25.7 MeV (d) 49.34 MeV

21. A radioactive isotope A with a half life of 1.25×10^{10} years decays into B which is stable. A sample of rock from a planet is found to contain both A and B present in the ratio 1 : 15. The age of the rock is

(a) 9.6×10^{10} years (b) 4.2×10^{10} years
(c) 5×10^{10} years (d) 1.95×10^{10} years

22. A heavy nucleus at rest breaks into two fragments which fly off with velocities in the ratio 3 : 1. The ratio of radii of the fragments is

(a) $1 : 3^{1/3}$ (b) $3^{1/3} : 4$ (c) 4 : 1 (d) 2 : 1

23. A radioactive nucleus emits 3α-particles and 5β-particles. The ratio of number of neutrons to that of protons will be

(a) $\frac{A-Z-12}{Z-6}$ (b) $\frac{A-Z}{Z-1}$
(c) $\frac{A-Z-11}{Z-6}$ (d) $\frac{A-Z-11}{Z-1}$

24. A radioactive sample has half life of 5 days. To decay from 8 microcurie to 1 microcurie, the number of days taken will be

(a) 40 (b) 25 (c) 15 (d) 10

25. A free neutron decays spontaneously into

(a) a proton, an electron and anti-neutrino
(b) a proton, an electron and a neutrino
(c) a proton and electron
(d) a proton, and electron, a neutrino and an anti-neutrino.

26. The radius of germanium (Ge) nuclide is measured to be twice the radius of ${}_4^9Be$. The number of nucleons in Ge are

(a) 72 (b) 73 (c) 74 (d) 75

27. Fusion reaction takes place at high temperature because

(a) nuclei break up at high temperature
(b) atoms get ionised at high temperature
(c) kinetic energy is high enough to overcome the coulomb repulsion between nuclei
(d) molecules break up at high temperature

28. Which of the following is more effective in inducing nuclear fission?

(a) Fast neutron (b) Fast proton
(c) Slow proton (d) Slow neutron

29. To generate power of 3.2 MW, the number of fissions of ${}^{235}U$ per minute is (Energy released per fission = 200 MeV, 1 eV = 1.6×10^{-19} J)

(a) 6×10^{18} (b) 6×10^{17}
(c) 10^{17} (d) 6×10^{16}

30. The ${}_{90}^{232}Th$ atom has successive alpha and beta decays to the end product ${}_{82}^{208}Pb$. The numbers of alpha and beta particles emitted in the process respectively are

(a) 4, 6 (b) 4, 4 (c) 6, 2 (d) 6, 4

31. A nucleus with mass number 220 initially at rest emits an α particle. If the Q value of the reaction is 5.5 MeV, the kinetic energy of the α particle is

(a) 4.4 MeV (b) 5.4 MeV
(c) 5.6 MeV (d) 6.5 MeV

32. An element X decays first by positron emission and then two α-particles are emitted in successive radioactive decay. If the product nucleus has mass number 227 and atomic number 89, the mass number and atomic number of element X are

(a) (273, 93) (b) (235, 94)
(c) (238, 93) (d) (237, 92)

33. The intensity of gamma radiation from a given source is I. On passing through 36 mm of lead, it is reduced to $\frac{I}{8}$. The thickness of lead which will reduce the intensity of $\frac{I}{2}$ will be

(a) 12 mm (b) 18 mm (c) 9 mm (d) 6 mm

34. F_{pp}, F_{nn} and F_{np} are the nuclear forces between proton-proton, neutron-neutron and neutron-proton respectively. Then relation between them is

(a) $F_{pp} = F_{nn} \neq F_{np}$ (b) $F_{pp} \neq F_{nn} = F_{np}$
(c) $F_{pp} = F_{nn} = F_{np}$ (d) $F_{pp} \neq F_{nn} \neq F_{np}$

35. A nucleus ${}_QX^P$ emits one α-particle and one β-particle. The mass number and atomic number of product nucleus are

(a) $(P-2)\,(Q+1)$ (b) $(P-3)\,(Q-1)$
(c) $(P-4)\,(Q-1)$ (d) $(P+4)\,(Q-1)$

36. Half lives of two isotopes X and Y of a material are known to be 2×10^9 years and 4×10^9 years respectively. If a planet was formed with equal number of these isotopes, estimate the current age of the planet, given that currently the material has 20% of X and 80% of Y by number.

(a) 2×10^9 years (b) 4×10^9 years
(c) 6×10^9 years (d) 8×10^9 years

37. An element A decays into an element C by a two step process.

$A \rightarrow B + {}_2He^4$ and $B \rightarrow C + 2e$. Then,

(a) A and C are isotopes
(b) A and C are isobars
(c) B and C are isotopes
(d) A and B are isobars

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38. A nucleus of Ux_1 has a half life of 24.1 days. How long a sample of Ux_1 will take to change to 90% of Ux_1.
(a) 80 days (b) 40 days (c) 20 days (d) 10 days

39. A nuclide 1 is said to be a mirror isobar of nuclide 2 if $Z_1 = N_2$ and $Z_2 = N_1$. What nuclide is a mirror isobar of $_{11}Na^{23}$?
(a) $_{10}Ne^{23}$ (b) $_{12}Mg^{23}$
(c) $_{13}Al^{25}$ (d) $_{13}Mg^{23}$

40. A heavy nucleus X of mass number 240 and binding energy per nucleon 7.6 MeV is split in to two fragments Y and Z of mass numbers 110 and 130. The binding energy of nucleus in Y and Z is 8.5 MeV per nucleon. The energy Q released per fission in MeV is
(a) 116 MeV (b) 216 MeV
(c) 306 MeV (d) 340 MeV

41. A radioactive isotope is being produced at a constant rate X. Half-life of the isotope is Y. After sometime, number of radioactive nuclei becomes constant. This constant number is
(a) $XY / \ln 2$ (b) XY
(c) $XY \ln 2$ (d) X / Y

42. When a radioactive isotope $_{88}Ra^{228}$ decay in series by the emission of 3α-particles and a β-particle, the isotope finally formed is
(a) $_{84}X^{228}$ (b) $_{86}X^{222}$
(c) $_{83}X^{216}$ (d) $_{83}X^{215}$

43. The mean lives of a radioactive sample are 30 years and 60 years for α-emission and β-emission respectively. If the sample decays both by α-emission and β-emission simultaneously, the time after which, only one-fourth of the sample remains is
(a) 14 years (b) 20 years (c) 28 years (d) 45 years

44. A mixture consists of two radioactive materials A_1 and A_2 with half lives of 20 s and 10 s respectively. Initially the mixture has 40 g of A_1 and 160 g of A_2. The amount of the two in the mixture will become equal after
(a) 60 s (b) 80 s (c) 20 s (d) 40 s

45. The power obtained in a reactor using U^{235} disintegration is 1000 kW. The mass decay of U^{235} per hour is
(a) 10 microgram (b) 20 microgram
(c) 40 microgram (d) 1 microgram

DAY 27 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____
(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (a) : Triton is the nucleus of a tritium atom.
$\therefore$ Triton = ${}_1H^3$
It has one proton and 2 neutrons.

2. (c) : Let $\lambda_A = \lambda \therefore \lambda_B = 2\lambda$
If N_0 is total number of atoms in A and B at $t = 0$, then initial rate of disintegration of $A = \lambda N_0$, and initial rate of disintegration of $B = 2\lambda N_0$

As $\lambda_B = 2\lambda_A \quad \left(\because \lambda = \frac{\ln 2}{T_{1/2}}\right)$

$\therefore \quad (T_{1/2})_B = \frac{1}{2}(T_{1/2})_A$

i.e., half-life of B is half the half-life of A.
After one half-life of A

$$\left(-\frac{dN}{dt}\right)_A = \frac{\lambda N_0}{2} \qquad \ldots(i)$$

Equivalently, after two half lives of B

$$\left(-\frac{dN}{dt}\right)_B = \frac{2\lambda N_0}{4} = \frac{\lambda N_0}{2} \qquad \ldots(ii)$$

From (i) and (ii), we get

$$\left(-\frac{dN}{dt}\right)_A = \left(-\frac{dN}{dt}\right)_B,$$

After $n = 1$, *i.e.*, one half-life of A, the rate of disintegration of both will be equal.

3. (a) : When four He nuclei are fused together, one oxygen nucleus is formed. The reaction is

$4\,{}^4_2\text{He} \rightarrow {}^{16}_8\text{O}$

Mass defect, $\Delta m = 4m_{\text{He}} - m_{\text{O}}$
$\therefore \quad \Delta m = 4 \times 4.0026 \text{ u} - 15.9994 \text{ u} = 0.011 \text{ u}$
Equivalent energy,
$E = \Delta mc^2 = 0.011 \times 931 \text{ MeV} = 10.24 \text{ MeV}$

4. (d): $m_0 = 10$ g, $t = 2\tau = 2 \times \frac{1}{\lambda} = \frac{2}{\lambda} \quad \left(\because \tau = \frac{1}{\lambda}\right)$

$$\frac{N}{N_0} = \frac{m}{m_0} = e^{-\lambda t} = e^{-\lambda(2/\lambda)} = e^{-2}$$

$$\therefore \quad m = \frac{m_0}{e^2} = \frac{10}{(2.72)^2} = 1.35 \text{ g}$$

5. (d): Activity reduces from 6000 dps to 3000 dps in 140 days. It implies that half life of the radioactive sample is 140 days.
In 280 days (or two half lives), activity will become $\left(\frac{1}{4}\right)^{\text{th}}$ of the initial activity. As the activity left is 6000 dps, therefore, initial activity of the sample
$= 4 \times 6000 = 24000$ dps.

6. (b): As $N = N_0 e^{-\lambda t}$ or $\frac{N}{N_0} = e^{-\lambda t}$

Taking natural logarithm on both sides, we get

$$-\lambda t = \ln\frac{N}{N_0} \text{ or } \lambda t = \ln\frac{N_0}{N} \text{ or } t = \frac{1}{\lambda}\ln\frac{N_0}{N}$$

Here, $\lambda = \frac{\ln 2}{T_{1/2}} = \frac{0.693}{3.8} = 0.182, \frac{N}{N_0} = \frac{1}{20}$

$$\therefore \quad t = \frac{1}{0.182}\ln(20) = 16.5 \text{ days}$$

7. (a) : Mean life, $\tau = \frac{1}{\lambda}$

and half life $T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$

$\therefore \quad \tau > T_{1/2}$. Greater fraction will decay in longer time.

8. (c) : As $\frac{N}{N_0} = \left(\frac{1}{2}\right)^{t/T_{1/2}}$

Here, $t = \frac{T_{1/2}}{2}$ or $\frac{t}{T_{1/2}} = \frac{1}{2}$

$$\therefore \quad \frac{N}{N_0} = \left(\frac{1}{2}\right)^{t/T_{1/2}} = \left(\frac{1}{2}\right)^{1/2} = \frac{1}{\sqrt{2}}$$

9. (b): Here, $m_p = 1.007825$ u, $m_n = 1.008665$ u
mass of ${}_1H^2$ nucleus, $m_N({}_1H^2) = 2.014102$ u
The deuteron nucleus contains one proton and one neutron.
Therefore, mass of nucleons constituting deuteron,
$m_p + m_n = 1.007825 + 1.008665 = 2.01649$ u
Mass defect, $\Delta M = (m_p + m_n) - m_N({}_1H^2)$
$= 2.01649 - 2.014102 = 0.002388$ u
$= 0.002388 \times 931.5 \text{ MeV/c}^2$
$= 2.224 \text{ MeV/c}^2$
Binding energy, $E_b = \Delta Mc^2 = 2.224$ MeV
Binding energy per nucleon

$$= \frac{E_b}{A} = \frac{2.224}{2} = 1.112 \text{ MeV}$$

10. (b): Let N be the number of nuclei at any time t. Then

$$\frac{dN}{dt} = 50 - \lambda N \text{ or } \frac{dN}{50 - \lambda N} = dt$$

Integrate both sides, we get

$$\int_0^N \frac{dN}{50 - \lambda N} = \int_0^t dt \quad \Rightarrow \quad -\frac{1}{\lambda}\left[\ln(50 - \lambda N)\right]_0^N = t$$

$$\ln\left(\frac{50 - \lambda N}{50}\right) = -\lambda t$$

$$\frac{50 - \lambda N}{50} = e^{-\lambda t}; \; 1 - \frac{\lambda N}{50} = e^{-\lambda t}$$

$$N = \frac{50}{\lambda}\left(1 - e^{-\lambda t}\right)$$

As $N = 25$ and $\lambda = 0.5 \text{ s}^{-1}$

$$25 = \frac{50}{0.5}(1 - e^{-0.5t}), \; \frac{1}{4} = 1 - e^{-0.5t}$$

$$e^{-0.5t} = \frac{3}{4} \quad \therefore \quad t = 2\ln\left(\frac{4}{3}\right)$$

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11. (c) : Rate of disintegration is directly proportional to number of atoms left.

In case of source A, $\frac{N}{N_0}=\left(\frac{1}{2}\right)^2=\frac{1}{4}$

In case of source B, $\frac{N}{N_0}=\left(\frac{1}{2}\right)^1=\frac{1}{2}$

$\therefore \quad \frac{R_A}{R_B}=\frac{N_0/4}{N_0/2}=\frac{1}{2}$

12. (a) : Decrease in mass number due to two α
$= 2 \times 4 = 8$
Decrease in charge number due to two $\alpha = 4$
Increase in charge number due to one $\beta = 1$
Net decrease in charge number $= 4 - 1 = 3$
γ affects neither.
$\therefore$ For A_4, $A = 180 - 8 = 172$
$Z = 72 - 3 = 69$

13. (c) : $\frac{N}{N_0}=\left(\frac{1}{2}\right)^n=\frac{1}{16}$
$\because \quad n = 4$
$\therefore \quad t = nT_{1/2} = 4 \times 2 = 8$ h

14. (a) : Here $m_p = 1.007277$ amu
$m_n = 1.008665$ amu,
$m_{Li} = 7.016005$ amu,
Sum of the masses of three protons and four neutrons
$= 3m_p + 4m_n$
$= 3 \times 1.007277 + 4 \times 1.008665$
$= 3.021831 + 4.03466 = 7.056491$ amu
$\therefore$ Mass defect $= 7.056491 - 7.016005 = 0.040486$ amu

15. (b): According to radioactive decay, $N = N_0e^{-\lambda t}$
where, N_0 = Number of radioactive nuclei present in the sample at $t = 0$
N = Number of radioactive nuclei left undecayed after time t
λ = decay constant
For A, $N_A = (N_0)Ae^{-5\lambda t}$ ...(i)
For B, $N_B = (N_0)Be^{-\lambda t}$ ...(ii)
As per question $(N_0)_A = (N_0)_B$ (Given)
Dividing (i) by (ii), we get

$$\frac{N_A}{N_B}=\frac{e^{-5\lambda t}}{e^{-\lambda t}}=e^{-4\lambda t} \text{ or } \left(\frac{1}{e}\right)^2=e^{-4\lambda t} \text{ or } \frac{1}{e^2}=\frac{1}{e^{4\lambda t}}$$

$$e^{4\lambda t}=e^2 \text{ or } 4\lambda t=2 \text{ or } t=\frac{2}{4\lambda}=\frac{1}{2\lambda}$$

16. (b): According to radioactive decay law
$N = N_0e^{-\lambda t}$
where N_0 = Number of radioactive nuclei at time $t = 0$
N = Number of radioactive nuclei left undecayed at any time t
λ = decay constant

At time t_2, $\frac{2}{3}$ of the sample had decayed

$$\therefore \quad N=\frac{1}{3}N_0 \text{ or } \frac{1}{3}N_0=N_0e^{-\lambda t_2} \qquad \ldots(i)$$

At time t_1, $\frac{1}{3}$ of the sample had decayed,

$$\therefore \quad N=\frac{2}{3}N_0 \text{ or } \frac{2}{3}N_0=N_0e^{-\lambda t_1} \qquad \ldots(ii)$$

Divide (i) by (ii), we get

$$\frac{1}{2}=\frac{e^{-\lambda t_2}}{e^{-\lambda t_1}} \text{ or } \frac{1}{2}=e^{-\lambda(t_2-t_1)} \text{ or } \lambda(t_2-t_1)=\ln 2$$

$$t_2-t_1=\frac{\ln 2}{\lambda}=\frac{\ln 2}{\left(\frac{\ln 2}{T_{1/2}}\right)} \qquad \left(\because \lambda=\frac{\ln 2}{T_{1/2}}\right)$$

$T_{1/2} = 50$ days

17. (b): The rate of disintegration R is given by
$R = R_0e^{-1}t$
where R_0 is the initial rate at $t = 0$

$$\therefore \quad \frac{R_0}{R}=e^{\lambda t}$$

Taking the natural logarithm on both sides, we get

$$\ln\left(\frac{R_0}{R}\right)=\lambda t \quad \text{or} \quad \lambda=\frac{1}{t}\ln\left(\frac{R_0}{R}\right)$$

According to problem, $R_0 = 5000$, $R = 1250$, $t = 5$ min

$$\therefore \quad \lambda=\frac{1}{5}\ln\left(\frac{5000}{2000}\right)=\frac{1}{5}\ln 4=\frac{2}{5}\ln 2=0.4\ln 2 \text{ min}^{-1}$$

18. (c)

19. (d): Activity at time t_1,

$$X=\lambda N_1=\frac{1}{\tau}N_1 \text{ or } N_1=\tau X \qquad \left(\because \tau=\frac{1}{\lambda}\right)$$

Activity at time t_2, $Y=\lambda N_2=\frac{1}{\tau}N_2$ or $N_2=\tau Y$

Therefore, the number of nuclei decayed during time interval $(t_1 - t_2)$ is
$N_1 - N_2 = \tau X - \tau Y = (X - Y)\tau$

20. (c) : The given nuclear reaction is
$4_1{}^1H \rightarrow {}^4_2He + 2e^+ + \text{Energy}$
The energy released during the process is
$Q = [4m(_1{}^1H) - m(^4_2He) - 2(me_+)]c^2$
$= [4 \times 1.007825 - 4.002603) - 2 \times 0.000548]u \times c^2$
$= [4.0313 - 4.002603 - 0.001096]u \times c^2$
$= (0.027601\ u)c^2 = (0.027601\ u)(931.5\ \text{MeV/u}) = 25.7$ MeV

21. (c) : According to Rutherford and Soddy law for radioactive decay,
Number of atoms remained undecayed after time t is
$N = N_0e^{-\lambda t}$

$$e^{\lambda t}=\frac{N_0}{N} \text{ or } \lambda t=\ln\frac{N_0}{N}$$

$$\text{or, } t=\frac{1}{\lambda}\ln\frac{N_0}{N} \text{ or, } t=\frac{T_{1/2}}{\ln 2}\ln\frac{N_0}{N}$$

$$=\frac{1.25\times10^{10}}{\ln 2}\ln\frac{16}{1}=\frac{1.25\times10^{10}\times4\times\ln 2}{\ln 2}$$

$= 5 \times 10^{10}$ years

22. (a) : As the heavy nucleus at rest breaks, therefore according to law of conservation of momentum, we get

$$m_1v_1 + m_2v_2 = 0 \text{ or } \frac{v_1}{v_2}=\frac{m_2}{m_1}=\frac{3}{1} \qquad \ldots. \text{ (i)}$$

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As nuclear density is same,

$$\therefore \quad \frac{m_1}{m_2} = \frac{\rho\frac{4}{3}\pi R_1^3}{\rho\frac{4}{3}\pi R_2^3} = \frac{R_1^3}{R_2^3} \quad \text{or} \quad \frac{R_1^3}{R_2^3} = \frac{m_1}{m_2} = \frac{1}{3} \qquad \text{(Using (i))}$$

$$\therefore \quad R_1 : R_2 = 1 : 3^{1/3}$$

23. (d): During the emission of α-particle, the mass number and atomic number decreases by four and two respectively. During the emission of β-particle the mass number remains the same while the atomic number increases by 1.

$$^{A}_{Z}X \xrightarrow{3\alpha} {}^{(A-12)}_{(Z-6)}Y \xrightarrow{5\beta} {}^{(A-12)}_{(Z-1)}Y'$$

$$\therefore \quad \frac{\text{No. of neutrons}}{\text{No. of protons}} = \frac{A-12-(Z-1)}{Z-1} = \frac{A-Z-11}{Z-1}$$

24. (c) : Here,
Half life, $T_{1/2} = 5$ days
Initial activity, $R_0 = 1$ microcurie
Final activity, $R = 8$ microcurie

As $\frac{R}{R_0} = \left(\frac{1}{2}\right)^n$ where n is the no. of half lives

$$\therefore \quad \left(\frac{1}{8}\right) = \left(\frac{1}{2}\right)^n \text{ or } \left(\frac{1}{2}\right)^3 = \left(\frac{1}{2}\right)^n \text{ or } n = 3$$

As $n = \frac{t}{T_{1/2}}$ or $t = nT_{1/2} = (3)(5 \text{ days}) = 15$ days

25. (a) : A free neutron is unstable. It decays spontaneously into a proton, an electron and anti-neutrino.

$$\underset{\text{neutron}}{n} \rightarrow \underset{\text{proton}}{p} + \underset{\text{electron}}{e^-} + \underset{\text{anti-neutrino}}{\bar{\upsilon}}$$

26. (a) : Nuclear radii, $R = R_0(A)^{1/3}$ (where $R_0 = 1.2$ fm)
or $R \propto (A)^{1/3}$

$$\therefore \quad \frac{R_{Be}}{R_{Ge}} = \frac{(9)^{1/3}}{(A)^{1/3}} \text{ or } \frac{R_{Be}}{2R_{Be}} = \frac{(9)^{1/3}}{(A)^{1/3}}$$

$$\therefore \quad (A)^{1/3} = 2 \times (9)^{1/3}$$

or $A = 2^3 \times 9 = 72$
The number of nucleons in Ge is 72.

27. (c) : For fusion to take place, high temperature is needed because at high temperature, the kinetic energy becomes large enough to overcome the coulomb repulsion between nuclei.

28. (d)

29. (a) : Here, Power = 3.2 MW = 3.2×10^6 W
Energy released per fission = 200 MeV
$= 200 \times 10^6$ eV $= 200 \times 10^6 \times 1.6 \times 10^{-19}$ J

$$\text{Number of fissions per minute} = \frac{3.2 \times 10^6 \times 60}{200 \times 10^6 \times 1.6 \times 10^{-19}}$$
$$= 6 \times 10^{18}$$

30. (d): Let number of α particles emitted be x and number of β particles emitted be y.
Difference in mass number = $4x = 232 - 208 = 24$ or $x = 6$
Difference in charge number = $2x - y = 90 - 82 = 8$
$12 - y = 8$ or $y = 4$

31. (b): Here, $A = 220$, $Q = 5.5$ MeV
The kinetic energy of the α particle is

$$KE_\alpha = \frac{A-4}{A}Q = \frac{220-4}{220} \times 5.5 \text{ MeV} = 5.4 \text{ MeV}$$

32. (b): Let A and Z be mass number and atomic number of element X.

$$^{A}_{Z}X \xrightarrow{\beta^+} {}^{A}_{Z-1}Y \xrightarrow{2\alpha} {}^{A-8}_{Z-5}Y'$$

Since the product nucleus has mass number 227 and atomic number 89.

$\therefore \quad A - 8 = 227$ or $A = 235$ and $Z - 5 = 89$ or $Z = 94$

33. (a) : As $I = I_0 e^{-\mu x}$

$$\therefore \quad \frac{1}{8} = e^{-\mu 36} \qquad \text{.... (i)}$$

$$\text{and } \frac{1}{2} = e^{-\mu x} \qquad \text{.... (ii)}$$

From Eq. (i), we get

$$\left(\frac{1}{2}\right)^3 = e^{-\mu 36}$$

Using (ii), we get

or $e^{-3\mu x} = e^{-\mu 36}$ or $x = \frac{36}{3} = 12$ mm

34. (c) : Nuclear force is charge independent.

$$\therefore \quad F_{pp} = F_{nn} = F_{np}$$

35. (c) : After one α decay,

$${}_{Q}X^{P} \rightarrow {}_{Q-2}Y^{P-4} + {}_{2}He^{4} + Q$$

After one β decay

$${}_{Q-2}Y^{P-4} \rightarrow {}_{(Q-2)+1}Z^{P-4} + {}_{-1}e^{0} + Q$$

So, the mass number and atomic number of product nucleus are $(P - 4)$ and $(Q - 1)$.

36. (d): Let total sum of number of isotopes at the formation of the planet was N_0 and currently is N

$$\therefore \quad N_X = \left(\frac{N_0}{2}\right)e^{-\lambda_1 t} = 0.2N \qquad \text{.....(i)}$$

$$\text{and } N_Y = \left(\frac{N_0}{2}\right)e^{-\lambda_2 t} = 0.8N \qquad \text{.....(ii)}$$

Dividing equation (ii) by (i)

$$e^{(\lambda_1 - \lambda_2)t} = 4$$

or $(\lambda_1 - \lambda_2)t = \ln 4$

$$\therefore \quad \frac{\ln 2}{10^9}\left[\frac{1}{2} - \frac{1}{4}\right]t = 2\ln 2 \qquad \left(\because T_{1/2} = \frac{\ln 2}{\lambda}\right)$$

$\therefore \quad t = 8 \times 10^9$ years

37. (a) : A and C will be having same atomic number.

38. (a) : Here, $\lambda = \frac{0.693}{T_{1/2}} = \frac{0.693}{24.1} = 0.02876 \text{ day}^{-1}$

$$N = N_0 - 90\% \text{ of } N_0 = \frac{N_0}{10}$$

As $N = N_0 e^{-\lambda t}$

$$\therefore \quad \frac{N_0}{10} = N_0 e^{-\lambda t} \quad \text{or} \quad \frac{1}{10} = e^{-\lambda t} \text{ or } 10 = e^{\lambda t}$$

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or $\log_e 10 = \lambda t$

$$\therefore \quad t = \frac{1}{\lambda}\log_e 10 = \frac{2.303\log 10}{0.02870}$$

$$= \frac{2.303\times 1}{0.02876} = 80 \text{ days}$$

39. (b): A nuclide 1 is said to be mirror isobar of nuclide 2, if $Z_1 = N_2$ and $Z_2 = N_1$

Now, in $_{11}Na^{23}$, $Z_1 = 11$, $N_1 = 23 - 11 = 12$

∴ Mirror isobar of $_{11}Na^{23}$ is $_{12}Mg^{23}$, for which $Z_2 = 12$ and $N_2 = 23 - 12 = 11$

40. (b)

41. (a) : The total number of nuclei is constant if $X = \lambda N$.

or $$X = \frac{\ln(2)N}{Y} \qquad \left(\because \lambda = \frac{\ln(2)}{T_{1/2}} \text{ and } T_{1/2} = Y\right)$$

$\Rightarrow$ $N = XY/\ln(2)$.

42. (c) : Decrease in mass number due to emission of 3α-particles and a β-particle = 3 × 4 = 12

Decrease in charge number in the process

= 3 × 2 – 1 = 5

∴ For the resulting element,

$A = 228 - 12 = 216$

$Z = 88 - 5 = 83$

Thus, final isotope is $_{83}X^{216}$

43. (c) : Here, $\lambda_{(\alpha+\beta)} = \lambda_\alpha + \lambda_\beta$

$$\frac{1}{\tau} = \frac{1}{\tau_\alpha} + \frac{1}{\tau_\beta} \qquad \left(\text{As } \lambda = \frac{1}{\tau}\right)$$

$$\Rightarrow \quad \frac{1}{\tau} = \frac{1}{30} + \frac{1}{60} = \frac{1}{20}$$

∴ $\tau = 20$ years.

Now, $T_{1/2} = \ln(2)\,\tau = 13.86$ years

One-fourth of sample will remain after 2 half life = 27.72 years.

44. (d): Here, $(T_{1/2})_1 = 20$ s, $(T_{1/2})_2 = 10$ s, $N_{01} = 40$ g, $N_{02} = 160$ g.

Let the amount of the two radioactive materials become equal after t s.

From, $\frac{N}{N_0} = \left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^{t/T_{1/2}}$, we get

$$N_1 = N_{01}\left(\frac{1}{2}\right)^{t/20} = 40\left(\frac{1}{2}\right)^{t/20}$$

$$N_2 = N_{02}\left(\frac{1}{2}\right)^{t/10} = 160\left(\frac{1}{2}\right)^{t/10}$$

As $N_1 = N_2$

$$\therefore \quad 40\left(\frac{1}{2}\right)^{t/20} = 160\left(\frac{1}{2}\right)^{t/10}$$

or $$\left(\frac{1}{2}\right)^{t/20} = 4\left(\frac{1}{2}\right)^{t/10} = \left(\frac{1}{2}\right)^{\frac{t}{10}-2}$$

$$\therefore \quad \frac{t}{20} = \frac{t}{10} - 2 \quad \therefore \quad t = 40 \text{ s}$$

45. (c) : According to Einstein's mass energy relation

$E = mc^2$ or $m = \frac{E}{c^2}$

Mass decay per second

$$= \frac{\Delta m}{\Delta t} = \frac{1}{c^2}\frac{\Delta E}{\Delta t} = \frac{P}{c^2} = \frac{1000\times 10^3 \text{ W}}{(3\times 10^8 \text{ m/s})^2}$$

$$= \frac{10^6}{9\times 10^{16}} \text{ kg/s}$$

Mass decay per hour

$$= \frac{\Delta m}{\Delta t}\times 60\times 60 = \left(\frac{10^6}{9\times 10^{16}} \text{ kg/s}\right)(3600 \text{ s})$$

$= 4 \times 10^{-8}$ kg $= 40 \times 10^{-6}$ g $= 40$ μg

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Semiconductor Electronics

Band theory of solids

Each electron in an atom has definite energy value. These definite energy values are called energy levels. In solids, atoms are closely packed. A solid crystal contains about 10^{23} atoms/cm^3. So each atom is in the electrostatic field of neighbouring atoms. So in solids where atoms are closely spaced, their atomic energy levels of the electrons broaden and give rise to energy bands. These bands are of two types : valence band and conduction band. For semiconductors and insulators, the energy bands which consist of closely spaced completely filled energy states at 0 K are called valence bands. The bands with higher energies are called conduction bands.

Forbidden energy gap (E_g) is the energy gap between the top of the highest valence band and bottom of the lowest conduction band.

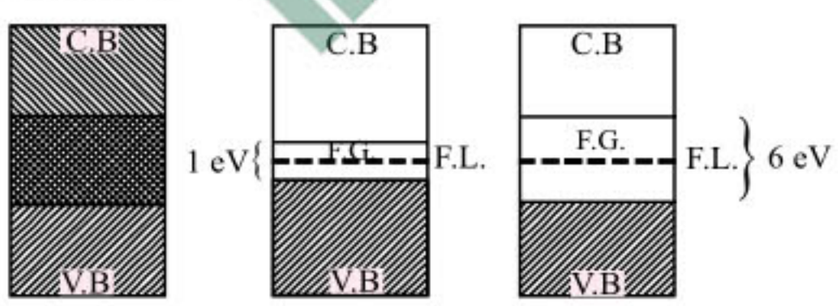
On the basis of band theory, solids are classified as follows:

Metals : In metals or good conductors, conduction band and valence band overlap each other. There is no forbidden energy gap.

Semiconductors : In semiconductors, the two energy bands are distinctly separate without any overlapping.

Insulators (Bad conductors) : The conduction band is empty and valence band is completely filled. The two bands are separated by forbidden energy gap about 6 eV energy.

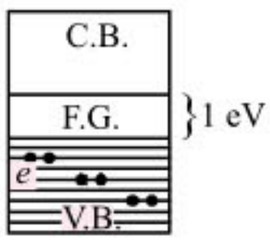
System of Units



Semiconductors

The substances whose electrical conductivity lies between conductors and insulators are **semiconductors.**

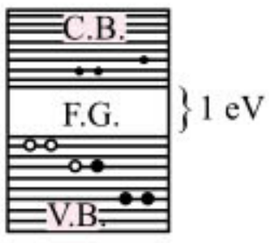
- The conductivity of semiconductors increases with increase in temperature.
- Semiconductors have negative temperature coefficient of resistivity *i.e.*, on increasing temperature, resistance decreases. For silicon, this coefficient is – 0.07 K^{-1}.
- The resistance of semiconductors decreases due to addition of impurities.
- At absolute zero temperature, no electron has adequate energy to jump over the forbidden gap and reach the conduction band. So, conduction band is completely empty.



At zero K

Therefore, semiconductor behaves as an insulator.

- At room temperature, some valence electrons acquire energy greater than energy gap 1 eV and jump to conduction band where they are free to move under the influence of even a small electric field. Due to this, semiconductors gains small conductivity at room temperature.



At room temp.

Intrinsic semiconductor

A semiconductor in pure form is called intrinsic semiconductor.

- Germanium (Ge) and silicon (Si) are important examples of intrinsic semiconductors. They are tetravalent elements. They have covalent bonding.
- A pure semiconductor has negative temperature coefficient of resistance. At ordinary temperature some electrons absorb energy from lattices and move to the conduction band. This happens due to breaking of covalent bond because of the effect of thermal energy. Electrons moving to the conduction band leave behind the vacancy of electron, called holes, in the valence band.
- Hole has positive charge equal to that of electron. Mobility of hole is smaller than that of electron.

The number density (n_e) of electrons in conduction band is equal to the number density (n_h) of holes in the valence band. $n_e = n_h = n_i$,

where n_i is called the intrinsic carrier concentration.

- When electric field is applied across an intrinsic semiconductor, electrons and holes move in opposite directions so that conventional current,

$$I = I_e + I_h$$

where I_e = free electron current and I_h = hole current.

- The deliberate addition of a desirable impurity to intrinsic semiconductor in controlled quantities to promote conductivity is called *doping*.

Extrinsic semiconductors

These are obtained by doping the pure semiconductor with small amount of certain impurities of either trivalent or pentavalent atoms.

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Extrinsic semiconductors are of two types:

***p*-type semiconductor :** When a trivalent impurity like B, Al, Ga or In is added to a pure semiconductor, semiconductor becomes deficient in electrons. *i.e.*, number of holes become more than number of electrons. Such a semiconductor is called *p*-type semiconductor.

- In the *p*-type semiconductors, holes are majority charge carriers, whereas electrons are minority charge carriers.
- In *p*-type semiconductor, the fermi level shifts towards the valence band.
- The trivalent impurity atoms are called acceptor atoms.

***n*-type semiconductor :** When a pentavalent impurity, such as P, As, Sb or Bi is added to a pure semiconductor the number of electrons become more than the holes in the semiconductor and such a semiconductor is called *n*-type semiconductor.

- It has electron as majority carriers and holes as minority carriers.
- In *n*-type semiconductor, the fermi level shifts towards the conduction band.
- The pentavalent impurity atoms are called donor atoms.

Charge density in a semiconductor

In *p*-type semiconductor, the number density of holes is approximately equal to that of acceptor atoms. $n_h \approx n_a$.

- In *n*-type semiconductor, the number of density of electrons is approximately equal to that of donor atoms. $n_e \approx n_d$.
- Under thermal equilibrium the product of the free negative and positive concentrations is a constant. It is independent of donor and acceptor impurity doping. This is called the **mass-action law** and is given by

$$n_e \cdot n_h = n_i^2.$$

Electrical conductivity of semiconductor (σ) : It is reciprocal of its resistivity (ρ) and is given by

$$\sigma = \frac{1}{\rho} = e(n_e\mu_e + n_h\mu_h)$$

where n_e, n_h are the number densities of electrons and holes and μ_e, μ_h are the mobilities of electrons and holes in the given semiconductor.

Effect of temperature : With the increase in temperature, more number of covalent bonds are broken, resulting large increase in current carrier concentration. Due to which the conductivity of semiconductor increases.

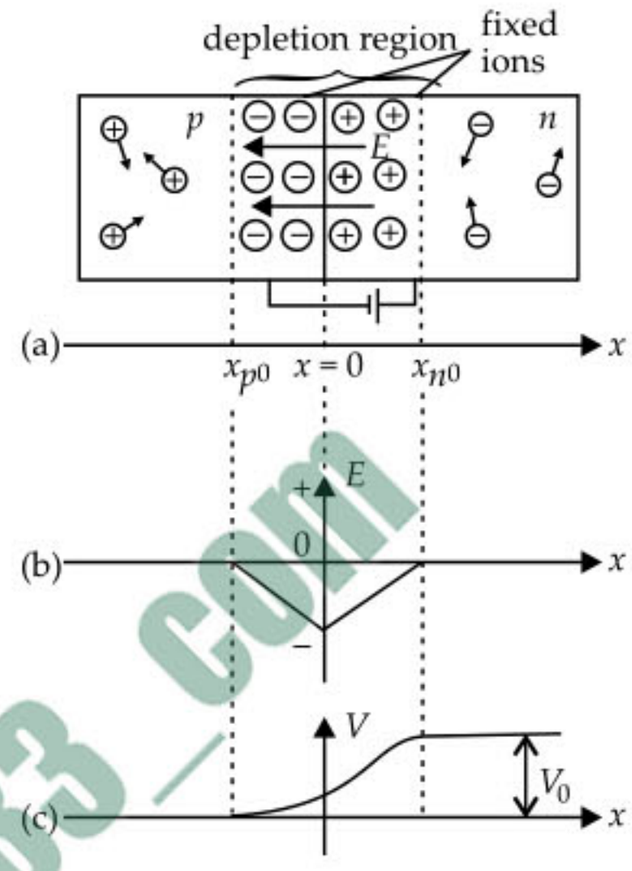
p-n Junction

The device obtained by growing a *p*-type semiconductor over a *n*-type semiconductor or vice-versa is called a *p*-*n* junction. It conducts in one direction only. It is also called a junction diode.

Depletion layer : The region at the junction that is depleted of mobile charges due to the formation of electric field across the width of junction which opposes any more diffusion of majority charge carriers on the two sides.

Depletion layer is also called potential barrier and its size is of the order of 10^{-6} m.

Electric field set up in the depletion region because of the potential barrier is directed from *n*-side to *p*-side. This potential barrier is generally 0.1 V to 0.3 V for germanium, and is of the order of 0.7 V for silicon. The potential barrier can be imagined due to a fictitious battery as shown below.



Drift current : If some how (thermal agitation for example) an electron-hole pair is created in the depletion region, electron is quickly pushed by the electric field (at the junction) towards *n*-side and the hole towards *p*-side. Hence a current from *n*-side to *p*-side occurs, this current is called drift current.

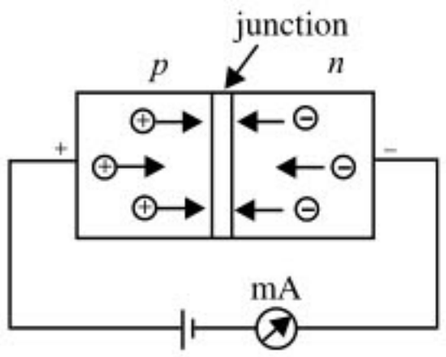
The drift current and the diffusion current are in opposite direction and for steady state, they are equal in magnitude.

Biasing of p-n junction

p-*n* junction diode can be operated in two modes.

Forward bias:

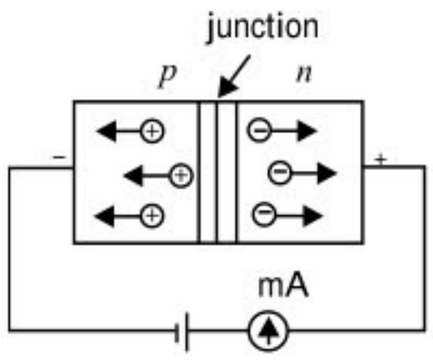
p-side of the junction diode is connected to the positive terminal and *n*-side is connected to the negative terminal of the battery. External field applied opposes the field due to fictitious battery.



Potential barrier, and hence the width of depletion region decrease and diffusion current increases.

Reverse bias

p-side of the junction is connected to the negative terminal and its *n*-side is connected to the positive terminal of the battery.



Potential barrier and hence width of depletion region increases during this mode. A small current of the order of microamperes flows due to the diffusion of minority carriers. This current is from *n*-side to *p*-side.

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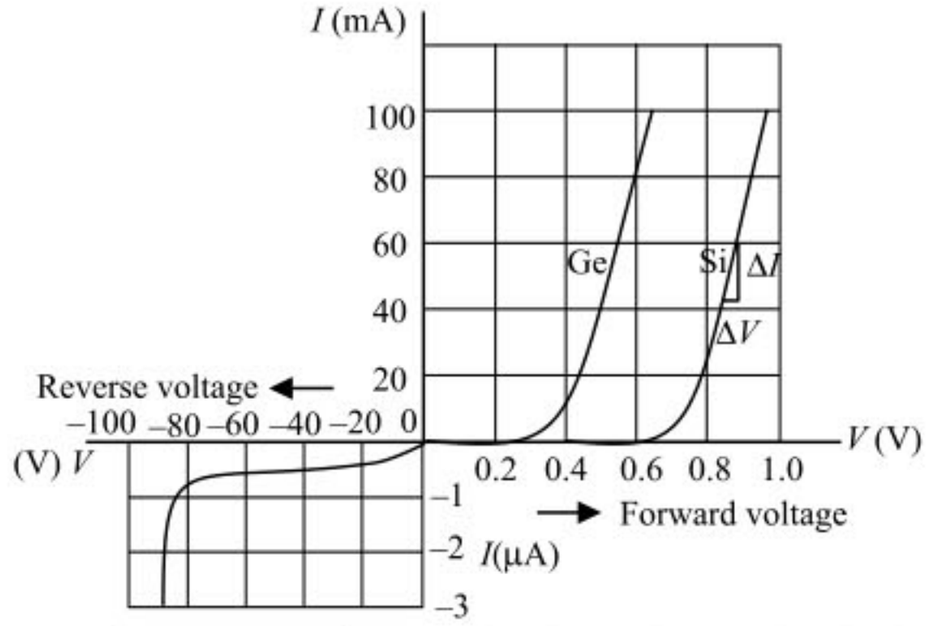
I-V characteristics of a *p-n* junction



Knee voltage : It is forward voltage beyond which the current through the junction starts to increase rapidly with the linear variation. But below the knee voltage, the characteristic curve is non-linear and diode current is almost zero.

Knee voltage for Si is 0.7 V and for Ge, it is 0.3 V.

Dynamic Resistance of a *p-n* junction diode is defined as

$$R = \frac{\Delta V}{\Delta I},$$

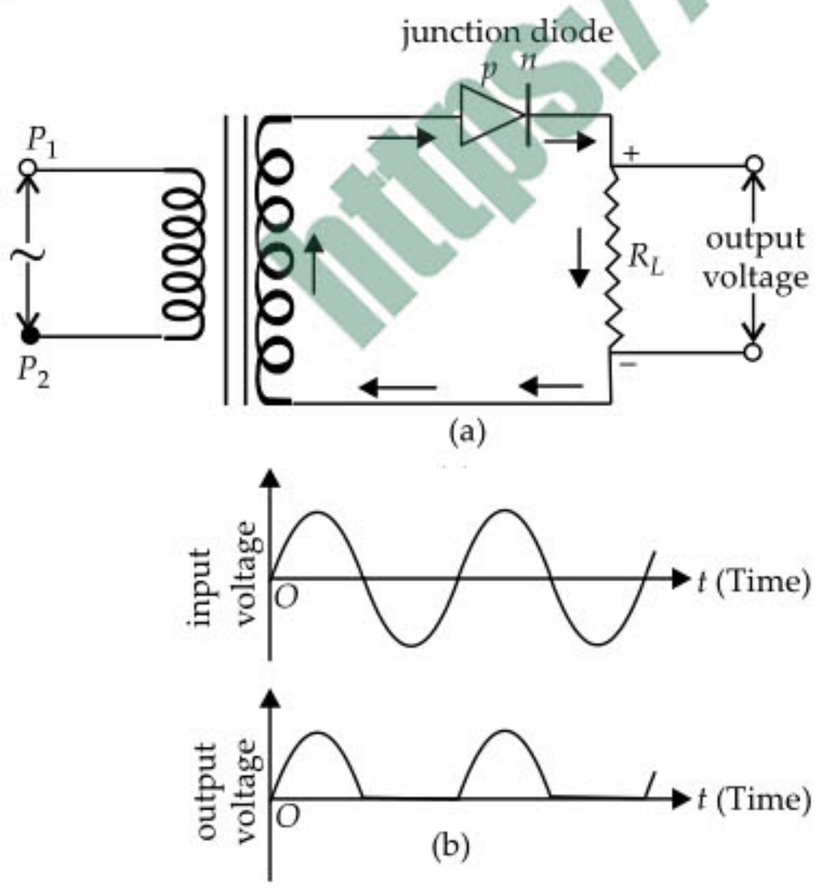
where ΔV denotes a small change in the applied voltage and ΔI is the corresponding small change in the current.

A *p-n* junction diode can be used as a rectifier which converts the input from a A.C source in a D.C output.

Rectifiers

Half wave rectifier

p-n junction diode is connected in series to an a.c. input so that if it is forward biased during the positive half cycle and output is obtained through a load resistor R^L. It is reverse biased during the negative half cycle and no output is obtained. Thus output is like a pulsating d.c.



Peak alternating current through load

$$I_m = \frac{V_m}{(r_f + R_L)}$$

r_f = Forward resistance of the diode ; R_L = load resistance ; V_m = peak a.c. voltage.

Ripple factor

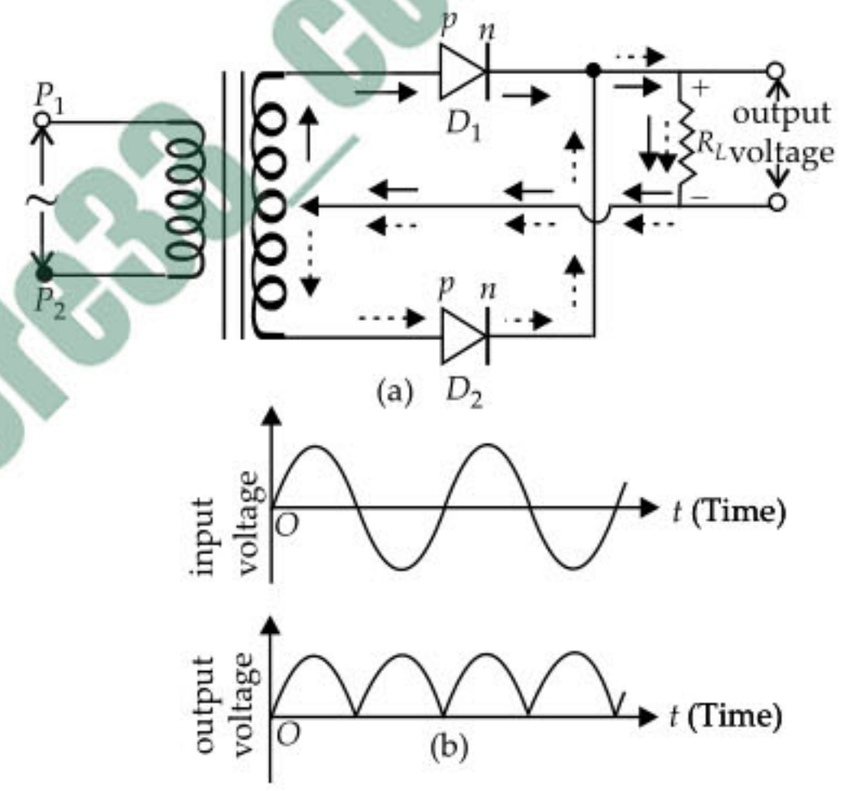
$$= \frac{\text{r.m.s value of a.c. component}}{\text{d.c. component in the rectifier circuit}} = 1.21$$

Efficiency

$$= \frac{\text{d.c. output power of half wave rectifier}}{\text{a.c. power supplied to the rectifier}} = 40.6\%$$

Full wave rectifier

Two diodes are connected to an a.c. input in a centre-tap transformer in such a way that if one conducts during positive half cycle, the other conducts during the negative half cycle. The output for both diodes is obtained in same direction, thus both half cycles can be utilized here unlike half wave rectifier.



Peak alternating current through the load

$$I_m = \frac{V_m}{(r_f + R_L)}$$

V_m = Peak a.c. voltage supplied.

Ripple factor $= \frac{I_{a.c}}{I_{d.c}} = 0.48$ (almost half the ripple factor of H.W.R)

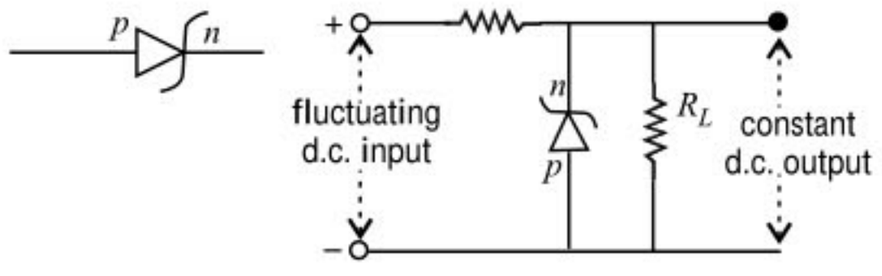
Efficiency $= \frac{P_{d.c}}{P_{a.c}} = 81.2\%$

(double the efficiency of H.W.R)

The pulsating d.c. obtained in both rectifiers mentioned above can be further rectified by using filter circuits.

Zener Diode

A zener diode is a device, which can be used as a constant voltage source. It is a semiconductor *p-n* junction (diode), which operates in the reverse break down region.



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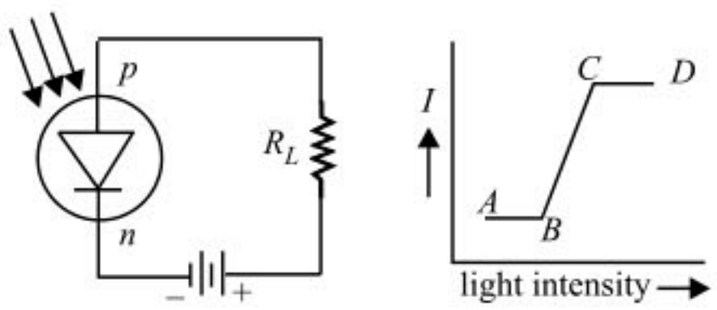
Zener diode are heavily doped, so that depletion layer is very narrow.

- Zener diode is used as voltage regulator.
- Zener diode in forward bias behaves like ordinary diode. It is always connected in reverse bias.

In reverse bias, zener diode has a sharp breakdown voltage called zener voltage. As a result, after the breakdown a large change in current can be produced by almost negligible change in reverse bias voltage across zener diode. So for widely different reverse currents, the voltage across the zener diode remains constant.

Photodiode

Photodiode is junction diode made from light sensitive semiconductor, whose resistance decreases on increasing the intensity of the light falling on it, thereby increasing the current through it.



If the photodiode is forward biased, a certain current flows in the circuit as depicted by portion *AB* of the graph. The current *AB*, that flows when no light is incident, is called dark current.

As the intensity of light is increased, the current goes on increasing as indicated by part *BC* in the graph.

When current does not increase with increase in intensity of light and the photodiode is saturated. Portion *CD* of graph shows saturation current.

The photo diodes are used in light detection system, high speed reading of computerised punched cards, reading of film sound tracks etc.

Solar Cell

Solar cell is a device for converting solar energy into electricity. It is based on the photovoltaic effect. One of the semiconductor regions is made so thin that the light incident reaches the *p-n* junction and gets absorbed. This generates potential difference across the junction.

Light Emitting Diodes (LED)

These are heavily doped *p-n* junction diodes made of compound semiconductors like gallium, arsenide phosphide or indium phosphide which when operated in forward bias mode, emit radiation in visible range.

The principle on which LED works is spontaneous emission of radiation, when an electron jumps from higher energy level to lower energy level in a semiconductor atom.

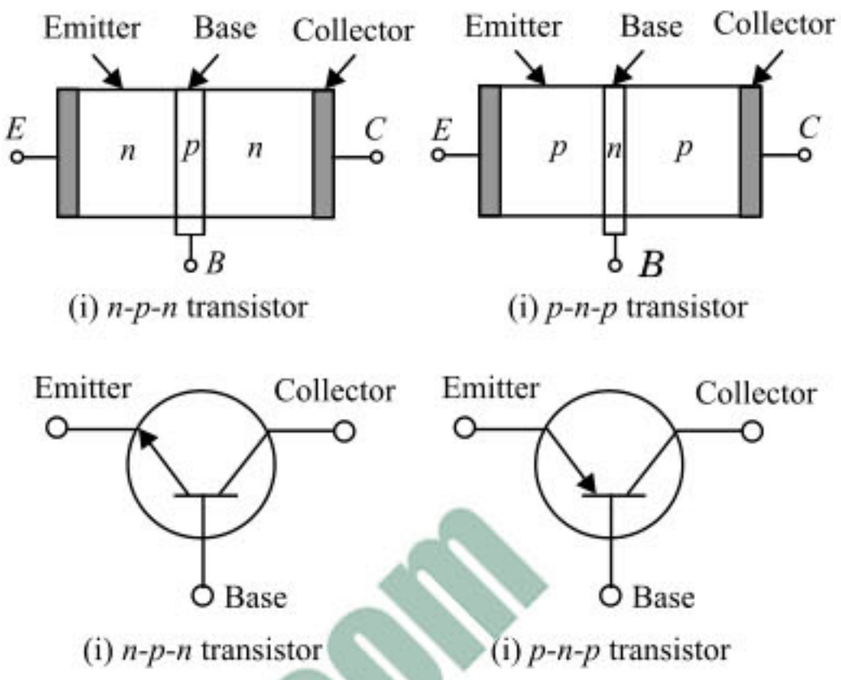
LEDs are used in traffic signal lights and in other electronic gadgets as indicator lights.

Transistor

A transistor consists of two *p-n* junctions formed by placing either *p*-type or *n*-type semiconductor between a pair of opposite types.

Junction transistors are of two types.

n-p-n transistor and *p-n-p* transistor



Emitter : This is the left hand block of the transistor. It is moderate in size and a heavily doped semiconductor. This supplies a large number of majority carriers for the current flow through the transistor.

Base : This is the central block. It is very thin and lightly doped.

Collector : This collects a major portion of the majority carriers supplied by the emitter. The collector side is moderately doped and larger in size as compared to the emitter.

In operation of a transistor, $I_E = I_B + I_C$

where I_E is emitter current, I_B is base current, I_C is the collector current.

A transistor can be operated in any one of the following three configurations.

- Common emitter (*CE*)
- Common base (*CB*)
- Common collector (*CC*)

Input characteristics of a transistor

The variation of the input current with the input voltage for a given output voltage is known as input characteristics of a transistor.

Output characteristics of a transistor

The variation of the output current with the output voltage for a given input current is known as output characteristics of a transistor.

Action of a transistor

A transistor has two junctions-emitter junction and a collector junction. There are four possible ways of biasing these two junctions as shown in the table.

Emitter junction	Collector junction	Region of operation
Forward biased	Reverse biased	Active
Forward biased	Forward biased	Saturation
Reverse biased	Reverse biased	Cut off
Reverse biased	Forward biased	Inverted

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Transistor as a switch

When the transistor is used in the cut off region or saturation region, it acts as a switch.

Transistor as an Amplifier

When the transistor is used in the active region, it acts as an amplifier.

Common Emitter Amplifier

In the common emitter transistor amplifier, the input signal voltage and the output collector voltage are 180° out of phase.

dc current gain

It is defined as the ratio of the collector current (I_C) to the base current (I_B).

$$\beta_{dc} = \frac{I_C}{I_B}$$

ac current gain

It is defined as ratio of change in collector current (ΔI_C) to the change in base current (ΔI_B).

$$\beta_{ac} = \frac{\Delta I_C}{\Delta I_B}$$

Voltage gain

It is defined as the ratio of output voltage to the input voltage.

$$A_v = \frac{V_o}{V_i} = -\beta_{ac} \times \frac{R_o}{R_i}$$

where R_o and R_i are the output and input resistances.

–ve sign represents that output voltage is opposite in phase with the input voltage.

Power gain

It is defined as the ratio of the output power to the input power.

$$A_p = \frac{\text{output power } (P_o)}{\text{input power } (P_i)}$$

$$= \beta^{ac} \times A_v$$

Note : Voltage gain (in dB) $= 20 \log_{10} \frac{V_o}{V_i} = 20 \log_{10} A_v$

Power gain (in dB) $= 10 \log \frac{P_o}{P_i}$

Common Base Amplifier

In common base transistor amplifier, the input signal voltage and the output collector voltage are in the same phase.

dc current gain

It is defined as the ratio of collector current (I_C) to the emitter current (I_E).

$$\alpha_{dc} = \frac{I_C}{I_E}$$

ac current gain

It is defined as the ratio of change in collector current (ΔI_C) to the change in emitter current (ΔI_E).

$$\alpha_{ac} = \left(\frac{\Delta I_C}{\Delta I_E}\right)$$

Voltage gain

It is defined as the ratio of output voltage to the input voltage.

$$A_v = \frac{V_o}{V_i} = \alpha_{ac} \times \frac{R_o}{R_i}$$

Power gain

It is defined as the ratio of output power to the input power.

$$A_p = \frac{\text{output power } (P_o)}{\text{input power } (P_i)}$$

$$= \alpha^{ac} \times A_v$$

Relationship between α and β

$$\beta = \frac{\alpha}{1-\alpha} \; ; \; \alpha = \frac{\beta}{1+\beta}$$

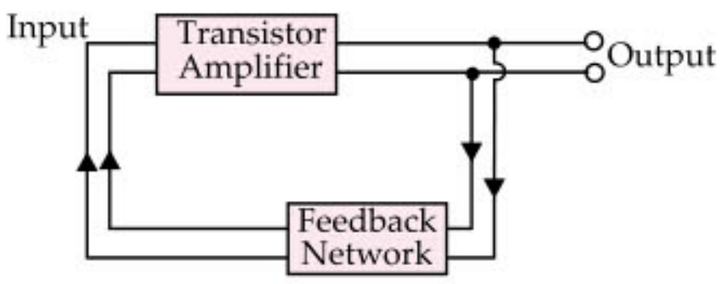
Transistor as an Oscillator

A transistor can be used as an oscillator.

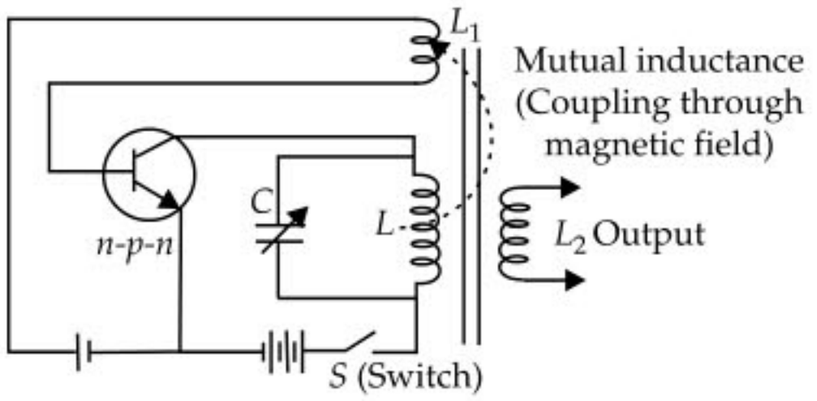
An oscillator generates ac output signal without any input ac signal.

An oscillator is a self sustained amplifier in which a part of output is fed back to the input in the same phase (this process is called positive feedback).

The block diagram of an oscillator is shown in the figure.



The circuit diagram of the tuned collector oscillator is shown in the figure below.



The frequency of the oscillation is given by

$$\upsilon = \frac{1}{2\pi\sqrt{LC}}$$

Logic Gates

These are electronic circuits which evaluate particular logical functions. Such circuits have one or more inputs and one output which can show only two states ; either 1(high) or 0(low).

Basic logic gates are of three types :

OR gate $Y = A + B$ → Y is high if any one or all of the inputs are high.

AND gate $Y = A \cdot B$ → Y is high only when all the inputs are high

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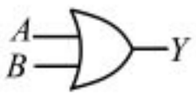
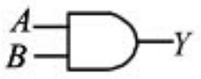
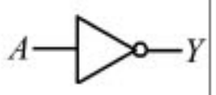
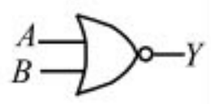
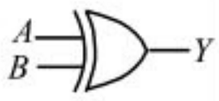
NOT gate $Y = \overline{A}$ → Y is inverse of the input A. If A is high, Y is low and vice versa.

Name of gate	Symbol	Truth Table	Boolean expression
OR		A B Y 0 0 0 0 1 1 1 0 1 1 1 1	$Y = A + B$
AND		A B Y 0 0 0 0 1 0 1 0 0 1 1 1	$Y = A \cdot B$
NOT		A Y 0 1 1 0	$Y = \overline{A}$
NAND		A B Y 0 0 1 0 1 1 1 0 1 1 1 0	$Y = \overline{A \cdot B}$
NOR		A B Y 0 0 1 0 1 0 1 0 0 1 1 0	$Y = \overline{A + B}$
XOR (also called exclusive OR gate)		A B Y 0 0 0 0 1 1 1 0 1 1 1 0	$Y = A \cdot \overline{B} + \overline{A} \cdot B$
XNOR		A B Y 0 0 1 0 1 0 1 0 0 1 1 1	$Y = A \cdot B + \overline{A} \cdot \overline{B}$

NAND gate and NOR gate are called universal gates because output for all other gates can be obtained using these gates.

De-Morgan's Theorems

$$\overline{A + B} = \overline{A} \cdot \overline{B}$$
$$\overline{A \cdot B} = \overline{A} + \overline{B}$$

Some Boolean indentities

$$A + \overline{A} \cdot B = A + B$$
$$A + (B \cdot C) = (A + B) \cdot (A + C)$$
$$A \cdot (\overline{A} + B) = A \cdot B$$

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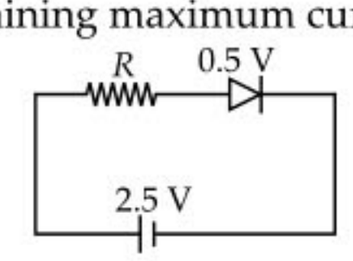
EXAM DRILL

1. A silicon specimen is made into a p-type semiconductor by doping on an average, one indium atom per 5×10^7 silicon atoms. If the number density of atoms in the silicon specimen is 5×10^{28} atoms m^{-3}, then the number of acceptor atoms in silicon per cubic centimetre will be

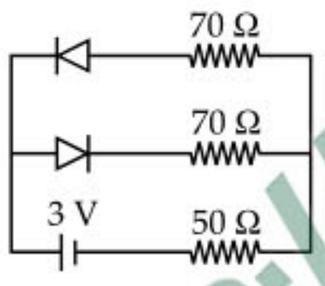
(a) 2.5×10^{30} (b) 2.5×10^{35}
(c) 1.0×10^{13} (d) 1.0×10^{15}

2. The diode used in the circuit shown in the figure has a constant voltage drop of 0.5 V at all currents and a maximum power rating of 100 mW. What should be the value of the resistance R connected in series with diode for obtaining maximum current?



(a) 2.5 Ω (b) 10 Ω (c) 12.5 Ω (d) 15 Ω

3. The circuit shown in the figure contains two diodes each with a forward resistance of 30 Ω and with infinite backward resistance. If the battery is 3 V, the current through the 50 Ω resistance is

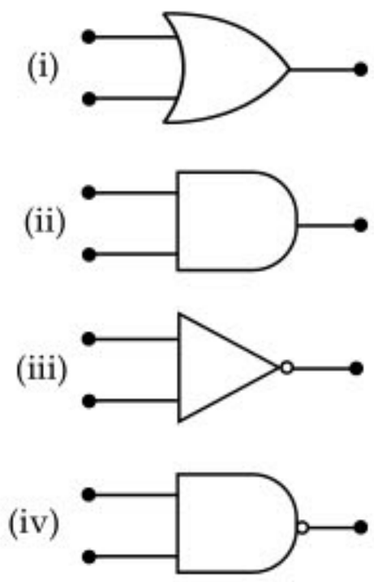


(a) zero (b) 0.01 A (c) 0.02 A (d) 0.03 A

4. A transistor is operated in common emitter configuration at V_C = 2 V such that a change in the base current from 100 μA to 300 μA produces a change in the collector current from 10 mA to 20 mA. The current gain is

(a) 50 (b) 75 (c) 100 (d) 25

5. Symbolic representation of four logic gates are shown as



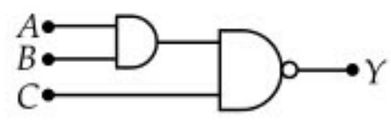
Pick out which ones are for AND, NAND and NOT gates, respectively

(a) (ii), (iii) and (iv) (b) (iii), (ii) and (i)
(c) (iii), (ii) and (iv) (d) (ii), (iv) and (iii)

6. In forward biasing of the p-n junction

(a) the positive terminal of the battery is connected to p-side and the depletion region becomes thick.
(b) the positive terminal of the battery is connected to n-side and the depletion region becomes thin.
(c) the positive terminal of the battery is connected to n-side and the depletion region becomes thick.
(d) the positive terminal of the battery is connected to p-side and the depletion region becomes thin.

7. The output Y, when all the three inputs are first high and then low, will respectively be



(a) 1, 0 (b) 1, 1 (c) 0, 0 (d) 0, 1

8. A common emitter amplifier has a voltage gain of 50, an input impedance of 100 Ω and an output impedance of 200 Ω. The power gain of the amplifier is

(a) 1000 (b) 1250 (c) 100 (d) 5000

9. Consider an n-p-n transistor amplifier in common emitter configuration. The current gain in the transistor is 100. If the collector current changes by 1 mA. What will be the change in emitter current?

(a) 1.1 mA (b) 1.01 mA
(c) 0.01 mA (d) 10 mA

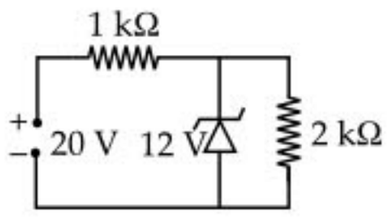
10. A light emitting diode (LED) has a voltage drop of 2 V across it and passes a current of 10 mA when it operates with a 6 V battery through a limiting resistor R. The value of R is

(a) 40 kΩ (b) 4 kΩ (c) 200 Ω (d) 400 Ω

11. The current gain in the common emitter mode of a transistor is 10. The input impedance is 20 kΩ and load of resistance is 100 kΩ. The power gain is

(a) 300 (b) 500 (c) 200 (d) 100

12. In the given circuit, the current through the resistor 2 kΩ is



(a) 2 mA (b) 4 mA (c) 6 mA (d) 1 mA

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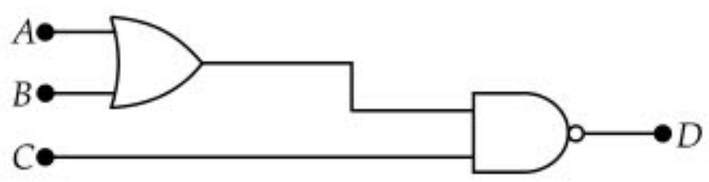
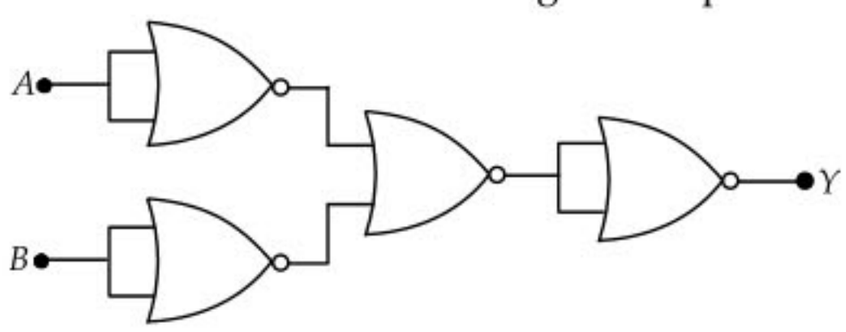
13. For the given combination of gates, if the logic states of inputs A, B, C are as follows $A = B = C = 0$ and $A = B = 1$, $C = 0$ then the logic states of output D are



(a) 0, 0 (b) 0, 1 (c) 1, 0 (d) 1, 1

14. The circuit as shown in the figure is equivalent to



(a) AND gate (b) NOR gate
(c) OR gate (d) NAND gate

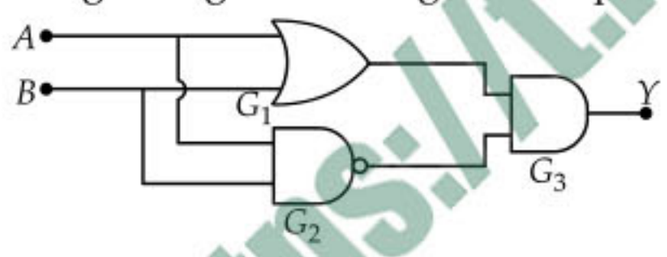
15. The current gain of a transistor in common-emitter mode is 49. The change in collector current and emitter current corresponding to the change in base current by 5.0 μA will be

(a) 245 μA, 250 μA (b) 240 μA, 235 μA
(c) 260 μA, 255 μA (d) none of these

16. In a common emitter amplifier, the resistance of the output circuit is 500 times the resistance of the input circuit. If $\alpha = 0.98$, then find the voltage gain and the power gain.

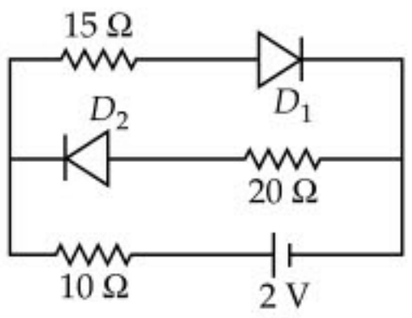
(a) 23500, 1300500 (b) 24500, 1200500
(c) 22505, 1300500 (d) 23500, 1200500

17. The following configuration of gates is equivalent to



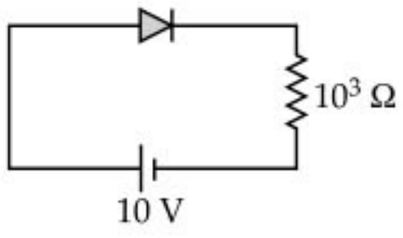
(a) NAND (b) XOR
(c) OR (d) AND

18. The current flowing through 10 Ω resistor in the circuit shown in the figure is



(a) 50 mA (b) 20 mA
(c) 40 mA (d) 80 mA

19. A junction diode is connected to a 10 V source and 10^3 Ω resistor as shown in figure. The slope of load line on the characteristic curve of diode will be



(a) 10^{-2} A V^{-1} (b) 10^{-3} A V^{-1}
(c) 10^{-4} A V^{-1} (d) 10^{-5} A V^{-1}

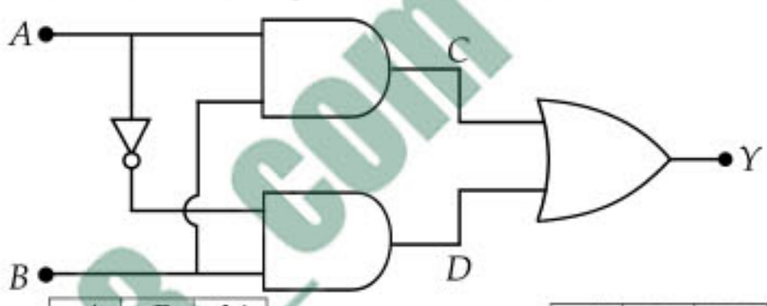
20. For a transistor amplifier in common emitter configuration for load impedance of 1 kΩ ($h_{fe} = 50$ and $h_{oe} = 25$ mA V^{-1}), the current gain is

(a) 5.2 (b) 15.7 (c) 24.8 (d) 48.78

21. In common emitter amplifier, the current gain is 62. The collector resistance and input resistance are 5 kΩ and 500 Ω respectively. If the input voltage is 0.01 V, the output voltage is

(a) 0.62 V (b) 6.2 V (c) 62 V (d) 0.01 V

22. Truth table for the given circuit is



(a)

A	B	Y
0	0	1
0	1	0
1	0	1
1	1	0

(b)

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

(c)

A	B	Y
0	0	0
0	1	1
1	0	0
1	1	1

(d)

A	B	Y
0	0	0
0	1	1
1	0	0
1	1	0

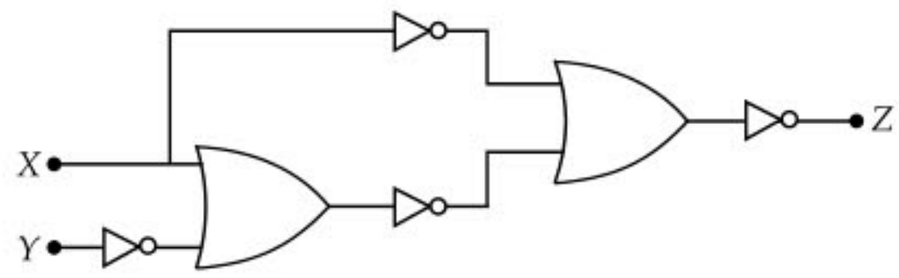
23. If an intrinsic semiconductor is heated, the ratio of free electrons to holes is

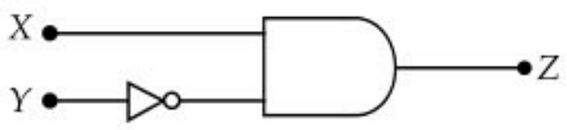
(a) greater than one (b) less than one
(c) equal to one
(d) decreases and becomes zero

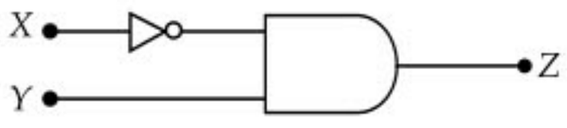
24. While a collector to emitter voltage is constant in a transistor, the collector current changes by 8.2 mA when the emitter current changes by 8.3 mA. The value of forward current ratio is

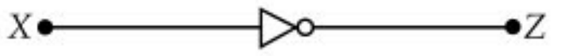
(a) 82 (b) 83 (c) 8.2 (d) 8.3

25. The logic circuit shown below is equivalent to



(a)


(b)


(c)


(d)

26. Consider the following statements A and B and identify the correct choice of the given answers.

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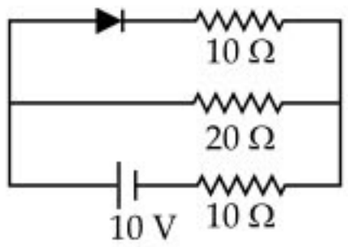
(A) The width of the depletion layer in a *p-n* junction diode increases in forward bias.
(B) In an intrinsic semiconductor the fermi energy level is exactly in the middle of the forbidden energy gap.

(a) A is true and B is false
(b) Both A and B are false
(c) A is false and B is true
(d) Both A and B are true

27. A common emitter transistor amplifier has a current gain of 50. If the load resistance is 4 kΩ and input resistance is 500 Ω, the voltage gain of the amplifier is
(a) 100 (b) 200 (c) 300 (d) 400

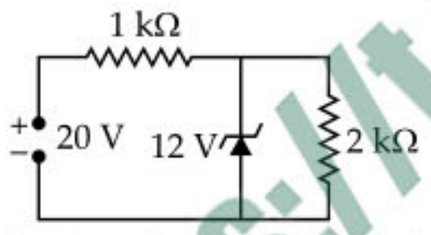
28. The voltage drop across a forward biased diode is 0.7 V. In the following circuit, the voltages across the 10 Ω resistance in series with the diode and 20 Ω resistance are



(a) 0.70 V, 4.28 V (b) 3.58 V, 4.28 V
(c) 5.35 V, 2.14 V (d) 3.58 V, 9.3 V

29. To obtain *p*-type extrinsic semiconductor, the impurity element to be added to germanium should be of valency
(a) 2 (b) 3 (c) 4 (d) 5

30. In the given circuit, the current through the resistor 2 kΩ is



(a) 2 mA (b) 4 mA (c) 6 mA (d) 10 mA

31. In a *p-n* junction photodiode, the value of the photo electromotive force produced by monochromatic light is proportional to
(a) the barrier voltage at *p-n* junction
(b) the intensity of light falling on the cell
(c) the frequency of light falling on the cell
(d) the voltage applied at the *p-n* junction.

32. Two pieces, one of germanium and the other of the aluminium are cooled from T_1 K to T_2 K. The resistance of
(a) aluminium increases and that of germanium decreases.
(b) each of them decreases.
(c) aluminium decreases and that of germanium increases.
(d) each of them increases.

33. Pure Si at 500 K has equal number of electron (n_e) and hole (n_h) concentrations of 1.5×10^{16} m^{-3}. Doping by indium increases n_h to 4.5×10^{22} m^{-3}. The doped semiconductor is of
(a) *n*-type with electron concentration $n_e = 5 \times 10^{22}$ m^{-3}.
(b) *p*-type with electron concentration $n_e = 2.5 \times 10^{10}$ m^{-3}.
(c) *n*-type with electron concentration $n_e = 2.5 \times 10^{23}$ m^{-3}.
(d) *p*-type having electron concentration $n_e = 5 \times 10^{9}$ m^{-3}.

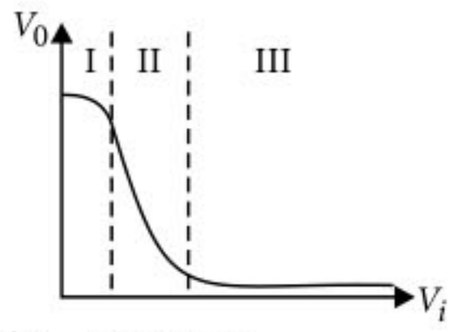
34. A full wave *p-n* diode rectifier uses a load resistor of 1500 Ω. No filter is used. The forward bias resistance of the diode is 10 Ω. The efficiency of the rectifier is
(a) 81.2% (b) 40.6% (c) 80.6% (d) 40.2%

35. Which of the following statements is correct for an *n*-type semiconductor?
(a) Holes are minority carriers and electrons are majority carriers and trivalent atoms are the dopants.
(b) Holes are majority carriers and electrons are minority carriers and trivalent atoms are the dopants.
(c) Holes are minority carriers and electrons are majority carriers and pentavalent atoms are the dopants.
(d) Holes are majority carriers and electrons are minority carriers and pentavalent atoms are the dopants.

36. The voltage gain of an amplifier with 9% negative feedback is 10. The voltage gain without feedback will be
(a) 90 (b) 100 (c) 9 (d) 10

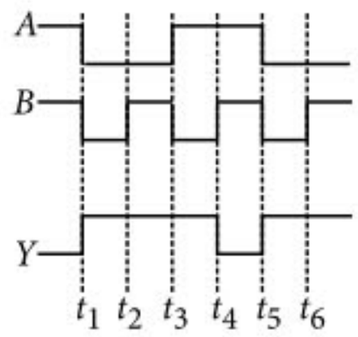
37. Which of the following elements when added as an impurity into the germanium produces a *p*-type semiconductor?
(a) P (b) As (c) Al (d) Sb

38. The transfer characteristics for a base biased transistor in *CE* configuration is as shown in the figure. For using transistor as an amplifier, it is used in



(a) region I (b) region II
(c) region III (d) both region I and III

39. The figure shows the voltage waveforms across two inputs *A* and *B* and the output *Y* of a logic circuit. The logic circuit gate is



(a) OR gate
(b) AND gate
(c) NOR gate
(d) NAND gate

40. In an *n-p-n* transistor amplifier, the collector current is 9 mA. If 90% of the electrons emitted reach the collector, then
(a) the emitter current is 1 mA.
(b) the base current is 10 mA.
(c) $\alpha = 0.9$, $\beta = 9.0$.
(d) $\alpha = 9.0$, $\beta = 0.9$.

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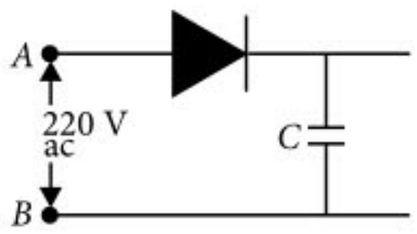
41. A 220 V ac supply is connected between points A and B as shown in the figure. The potential difference across the capacitor C is

(a) 0 V
(b) 110 V
(c) 220 V
(d) $220\sqrt{2}$ V



42. If the energy gap between valence band and conduction band is 10 eV, then the material is a/an

(a) metal (b) insulator
(c) semiconductor (d) superconductor

43. In the figure, the input waveform is converted into the output waveform by a device X. The device X is a/an

(a) amplifier (b) half wave rectifier
(c) full wave rectifier (d) oscillator

44. In figure, V_0 is the barrier potential across a p-n junction, when no battery is connected across the junction.

(a) 1 and 3 both correspond to forward bias of junction.
(b) 1 corresponds to reverse bias of junction and 3 corresponds to forward bias of junction.
(c) 1 corresponds to forward bias and 3 corresponds to reverse bias of junction.
(d) 1 and 3 both correspond to reverse bias of junction.

45. In a transistor if α varies between $\frac{20}{21}$ and $\frac{100}{101}$, then the value of β lies between

(a) 1–10 (b) 0.95–0.99
(c) 20–100 (d) 200–300

DAY 28 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____
(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. (d) : Number density of atoms in silicon specimen = 5×10^{28} atoms $m^{-3} = 5 \times 10^{22}$ atoms cm^{-3}. Since 1 atom of indium is doped in 5×10^7 silicon atoms, so total number of indium atoms doped per cm^3 of silicon will be

$$n = \frac{5\times10^{22}}{5\times10^{7}} = 1.0\times10^{15}$$

2. (b) : Voltage drop across diode, $V_d = 0.5$ V
Maximum power rating, $P = 100$ mW

$$= 100 \times 10^{-3} \text{ W} = 0.1 \text{ W}$$

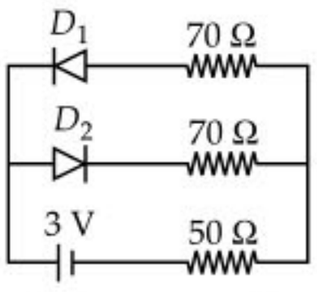
Diode resistance, $R_d = \frac{V_d^2}{P} = \frac{(0.5\text{ V})^2}{0.1\text{ W}} = 2.5\ \Omega$

Current in diode, $I_d = \frac{V_d}{R_d} = \frac{0.5\text{ V}}{2.5\ \Omega} = 0.2$ A

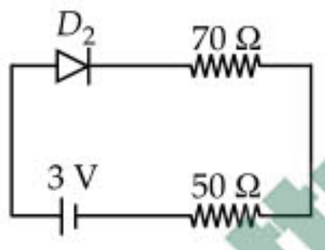
Total resistance of the circuit $= \frac{2.5\text{ V}}{0.2\text{ A}} = 12.5\ \Omega$

Resistance R in circuit, R = 12.5 W – 2.5 W = 10 W

3. (c) :



In the circuit the upper diode D_1 is reverse biased and the lower diode D_2 is forward biased. Thus there will be no current across upper diode junction. The effective circuit will be as shown in figure.

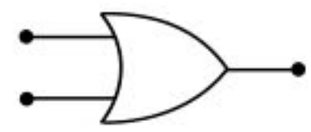


Total resistance of circuit
$R = 50\ \Omega + 70\ \Omega + 30\ \Omega = 150\ \Omega$
Current in circuit, $I = \frac{V}{R} = \frac{3\text{ V}}{150\ \Omega} = 0.02$ A

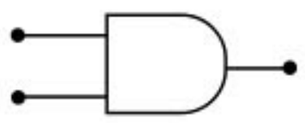
4. (a) : Current gain in common emitter transistor is

$$\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{(20-10)\text{ mA}}{(300-100)\ \mu\text{A}} = \frac{10\times10^{-3}\text{ A}}{200\times10^{-6}\text{ A}} = 50$$

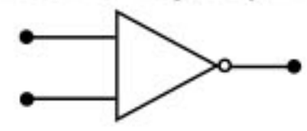
5. (d) :

(i) 

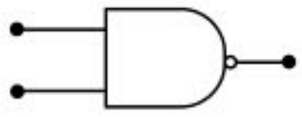
It represents logic symbol of OR gate.

(ii) 

It represents logic symbol of AND gate.

(iii) 

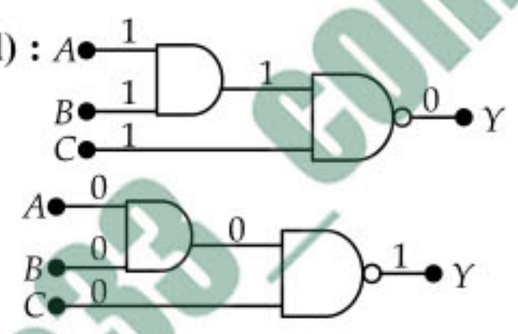
It represents the logic symbol of NOT gate.

(iv) 

It represents the logic symbol of NAND gate.

6. (d) : In forward biasing, the positive terminal of the battery is connected to *p*-side and the negative terminal to *n*-side of *p*-*n* junction. The forward bias voltage opposes the potential barrier. Due to it, the depletion region becomes thin.

7. (d) :



8. (b) : Here,
Voltage gain = 50
Input resistance, $R_i = 100$ W
Output resistance, $R_o = 200$ W

$$\text{Resistance gain} = \frac{R_o}{R_i} = \frac{200\ \Omega}{100\ \Omega} = 2$$

$$\text{Power gain} = \frac{(\text{Voltage gain})^2}{\text{Resistance gain}} = \frac{50\times50}{2} = 1250$$

9. (b) : Here, $\beta = 100$, $\Delta I_C = 1$ mA

$$\text{As } \alpha = \frac{\beta}{1+\beta} = \frac{100}{101}$$

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \quad \text{or} \quad \frac{100}{101} = \frac{1\text{ mA}}{\Delta I_E}$$

$$\therefore \quad \Delta I_E = 1.01\text{ mA}$$

10. (d) : As LED is connected to a battery through a resistance in series, hence the current flowing, is 10 mA(which is the same).
The voltage drop across LED = 2 V

As the battery has 6 V, the potential difference across R = 4 V

$$\therefore \quad IR = 4\text{ V or } R = \frac{4\text{ V}}{10\times10^{-3}\text{ A}} = 400\ \Omega$$

11. (b) : The power gain is defined as the ratio of change in output power to the change in input power.
Since, $P = VI$
Therefore,
Power gain = current gain × voltage gain

$$= \beta\times\beta\left(\frac{R_{out}}{R_{in}}\right) = \beta^2\left(\frac{R_{out}}{R_{in}}\right)$$

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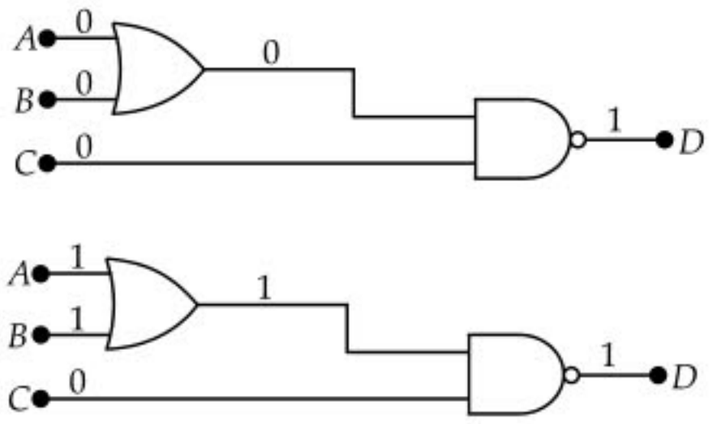
Here, $\beta = 10$, $R_{in} = 20\ k\Omega$, $R_{out} = 100\ k\Omega$

$\therefore$ Power gain $= (10)^2\left(\frac{100}{20}\right) = 100 \times 5 = 500$

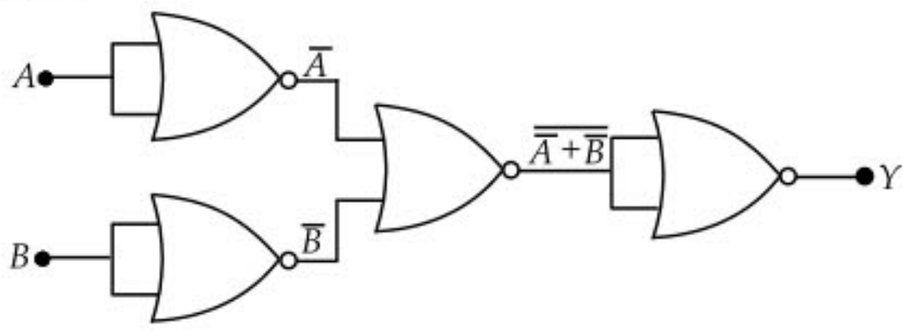
12. (c) : In the circuit, Zener diode is used as a voltage regulating device. Therefore, the current in the circuit,

$$I = \frac{12\ V}{2\ k\Omega} = 6 \times 10^{-3}\ A = 6\ mA$$

13. (d) :



14. (d) :



$$Y = \overline{\overline{\overline{A} + \overline{B}}} = \overline{A} + \overline{B} = \overline{A \cdot B}$$

It is a Boolean expression for NAND gate.

15. (a) : Here, $\beta = 49$, $\Delta I_B = 5.0\ \mu A$

$\therefore$ $\Delta I_C = \beta \Delta I_B = 49 \times 5.0\ \mu A = 245\ \mu A$

$\Delta I_E = \Delta I_B + \Delta I_C = 5.0\ \mu A + 245\ \mu A = 250\ \mu A$

16. (b) : Given $\alpha = 0.98$

and $\frac{R_{out}}{R_{in}} = 500$

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.98}{1-0.98} = 49$$

$$\text{Voltage gain} = (\beta)\left(\frac{R_{out}}{R_{in}}\right) = (49)(500) = 24500$$

$$\text{Power gain} = (\beta^2)\left(\frac{R_{out}}{R_{in}}\right) = (49)^2(500) = 1200500$$

17. (b) : Output of $G_1 = (A + B)$

Output of $G_2 = \overline{A \cdot B}$

Output of $G_3 = (A + B) \cdot \overline{A \cdot B}$

which gives XOR gate.

18. (d) : In the given circuit, junction diode D_1 is forward biased and will conduct whereas junction diode D_2 is reverse biased and will not conduct. Therefore current through 10 Ω resistor is

$$I = \frac{2\ V}{10\ \Omega + 15\ \Omega} = 0.08\ A = 80\ mA$$

19. (b) : If V is the voltage across the junction and I is the circuit current, then

$$V + IR = E \quad \text{or} \quad I = \frac{E}{R} - \frac{V}{R} = -\frac{V}{R} + \frac{E}{R}$$

$$\text{Slope of load line} = -\frac{1}{R} = \frac{1}{1000} = 10^{-3}\ A\ V^{-1}$$

20. (d) : For a transistor amplifier in common emitter configuration, current gain

$$A_i = \frac{h_{fe}}{1 + h_{oe}R_L}$$

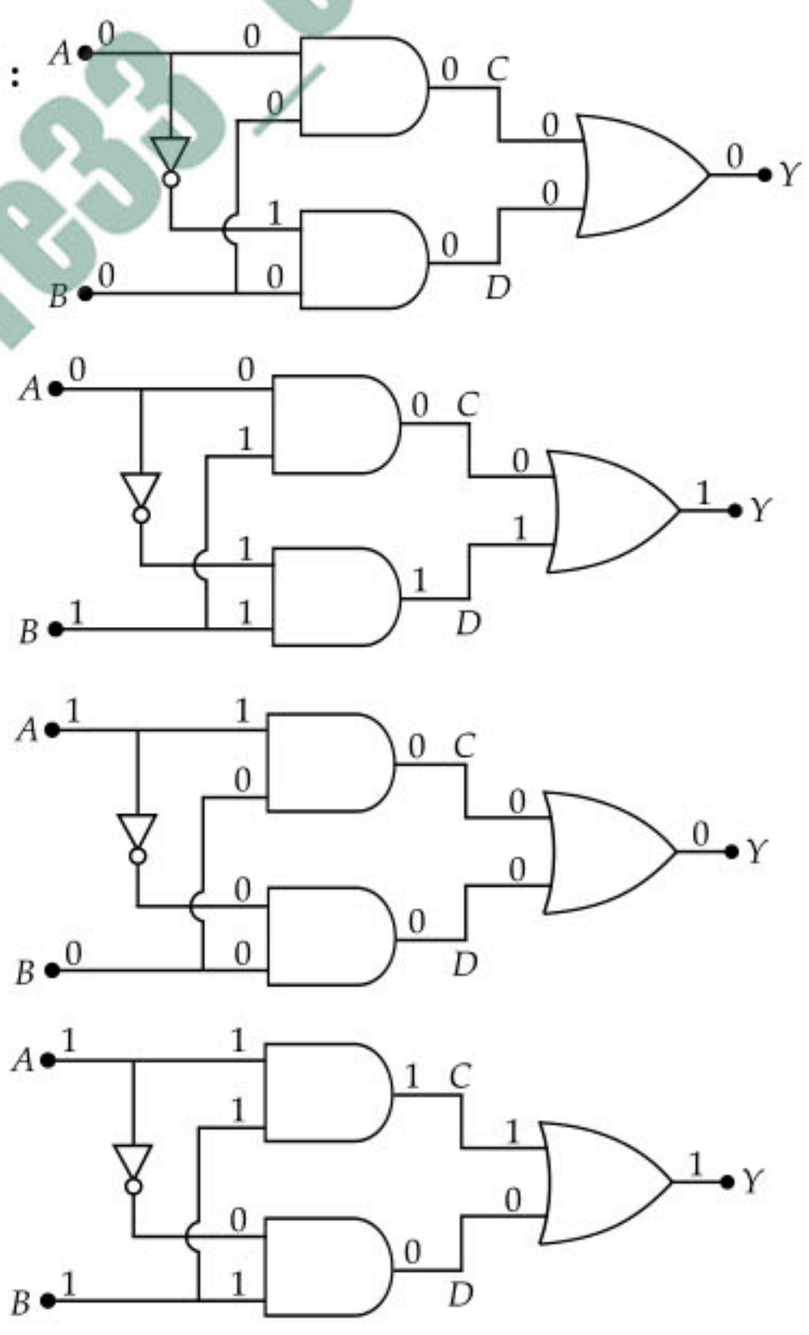
where h_{fe} and h_{oe} are hybrid parameters of a transistor.

$\therefore$ $A_i = \frac{50}{1 + 25 \times 10^{-6} \times 1 \times 10^3} = 48.78$

21. (b) : $\frac{V_o}{V_i} = \beta = \frac{R_o}{R_i} = \frac{62 \times 5 \times 10^3}{500} = 620$

$\therefore$ $V_o = 620\ V_i = 620 \times 0.01 = 6.2\ V$

22. (c) :



23. (c)

24. (a) : Here, $\Delta I_E = 8.3\ mA$

$\Delta I_C = 8.2\ mA$

As $\Delta I_E = \Delta I_B + \Delta I_C$

$\therefore$ $\Delta I_B = \Delta I_E - \Delta I_C = 8.3\ mA - 8.2\ mA = 0.1\ mA$

$$\text{Forward current ratio, } h_{fe} = \left[\frac{\Delta I_C}{\Delta I_B}\right]_{V_{CE}\ \text{is constant}}$$

$$= \left[\frac{8.2\ mA}{0.1\ mA}\right] = 82$$

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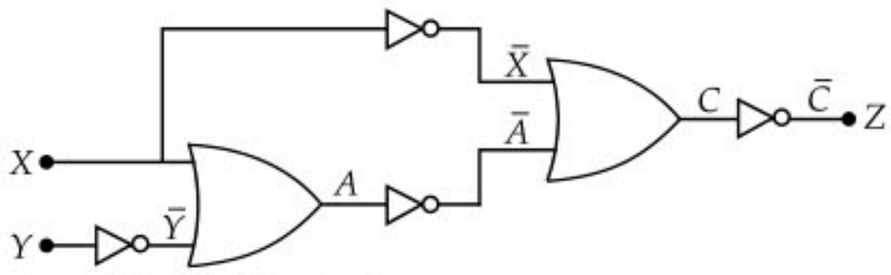
25. (d) :



Output of first OR gate is

$A = (X + \bar{Y})$

Inputs of second OR gate are $\bar{X}$ and $\bar{A}$.

Output of second OR gate is

$$C = \bar{X} + \bar{A}$$
$$= \bar{X} + \overline{X + \bar{Y}} = \bar{X} + (\bar{X} \cdot \bar{\bar{Y}}) = \bar{X} + (\bar{X} \cdot Y)$$
$$= \bar{X}(1 + Y) = \bar{X}$$

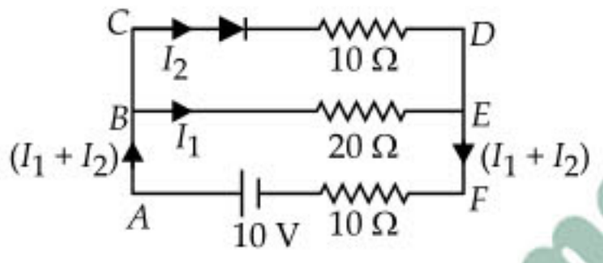
Final output is $Z = \bar{C} = \bar{\bar{X}} = X$

26. (c) : In a *p*-*n* junction the width of the depletion layer decreases in forward bias.

27. (d) : Here, $\beta = 50$, $R_L = 4\ \text{k}\Omega = 4 \times 10^3\ \Omega$ $R_i = 500\ \Omega$

Voltage gain, $A_v = \beta \dfrac{R_L}{R_i} = 50 \times \dfrac{4 \times 10^3}{500} = 400$

28. (b) : Let the currents through the 20Ω (parallel) and 10Ω (in series with the diode) be I_1 and I_2 respectively.



Applying Kirchhoff's second law for closed loop *ABEFA*, we get

$20I_1 + 10(I_1 + I_2) - 10 = 0$ .... (i)

Applying Kirchhoff's second law for closed loop *BCDEB*, we get

$0.7 + 10I_2 - 20I_1 = 0$ .... (ii)

Solving (i) and (ii), we get

$I_1 = 0.214$ A and $I_2 = 0.358$ A

Thus, voltage across the 10 Ω resistance in series with the diode = 0.358 A × 10 Ω = 3.58 V

And voltage across the 20 Ω resistance

= 0.214 A × 20 Ω = 4.28 V

29. (b) : To obtain *p*-type extrinsic semiconductor a trivalent impurity should be added to germanium.

30. (c) : In the circuit, Zener diode is used as a voltage regulating device. Therefore, the current in the

circuit, $I = \dfrac{12\ \text{V}}{2\ \text{k}\Omega} = 6 \times 10^{-3}\ \text{A} = 6\ \text{mA}$

31. (b) : In photodiode, the photoelectromotive force is produced by photo-voltaic action *i.e.* a potential difference is created between two points whose magnitude depends upon the intensity of incident light.

32. (c) : The temperature coefficient of resistance of aluminium is positive and of germanium is negative. Hence the resistance of aluminium decreases and that of germanium increases with decreases in temperature.

33. (d) : As $n_i^2 = n_e \times n_h$

$(1.5 \times 10^{16}\ \text{m}^{-3})^2 = n_e \times (4.5 \times 10^{22}\ \text{m}^{-3})$

$$\therefore \quad n_e = \frac{(1.5 \times 10^{16}\ \text{m}^{-3})^2}{(4.5 \times 10^{22}\ \text{m}^{-3})} = 5 \times 10^9\ \text{m}^{-3}$$

As $n_h >> n_e$, so semiconductor is *p*-type and

$n_e = 5 \times 10^9\ \text{m}^{-3}$.

34. (c) : Here, $r_i = 10\ \Omega$, $R_L = 1500\ \Omega$

Efficiency of the full wave rectifier is

$$\eta = \frac{P_{\text{dc}}}{P_{\text{ac}}} = \frac{(2I_m/\pi)^2 R_L}{(I_m/\sqrt{2})^2 (r_f + R_L)}$$

$$= \frac{0.812\ R_L}{r_f + R_L}$$

$$= \frac{0.812 \times 1500}{10 + 1500} = 0.806 = 80.6\%$$

35. (c) : In an *n*-type semiconductor, holes are minority carriers and electrons are majority carriers and pentavalent atoms are the dopants.

36. (b) : The voltage gain of the amplifier with negative feedback is

$$A' = \frac{A}{1 + \beta A}$$

where, A = voltage gain without feedback

β = feedback factor

Here, $A' = 10$, $\beta = 9\% = 0.09$

$$\therefore \quad 10 = \frac{A}{1 + 0.09A}$$

$10 + 0.9A = A$

$A(1 - 0.9) = 10$

$$A = \frac{10}{0.1} = 100$$

37. (c) : A *p*-type semiconductor is obtained when Si or Ge is doped with a trivalent impurity like indium (In), boron (B), aluminium (Al) etc. whereas an *n*-type semiconductor is obtained when Si or Ge is doped with a pentavalent impurity like arsenic (As), antimony (Sb), phosphorous (P) etc.

38. (b) : In the given graph,

Region (I) – Cutoff region

Region (II) – Active region

Region (III) – Saturation region

For using transistor as a switch it is used in cutoff region or saturation region.

For using transistor as a amplifier it is used in active region.

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39. (d) : The truth table of the given waveforms is as shown.

Time interval	Input A	Input B	Output Y
$< t_1$	1	1	0
t_1 to t_2	0	0	1
t_2 to t_3	0	1	1
t_3 to t_4	1	0	1
t_4 to t_5	1	1	0
t_5 to t_6	0	0	1
$> t_6$	0	1	1

As output $Y = \overline{A \cdot B}$

Hence the logic circuit represents NAND gate.

40. (c) : Here,

$$I_C = 9 \text{ mA} = \frac{90}{100} I_E$$

$\therefore \quad I_E = 10 \text{ mA}$

As $I_E = I_B + I_C$

$\therefore \quad I_B = I_E - I_C = 10 \text{ mA} - 9 \text{ mA} = 1 \text{ mA}$

$$\alpha = \frac{I_C}{I_E} = \frac{9 \text{ mA}}{10 \text{ mA}} = 0.9$$

$$\beta = \frac{I_C}{I_B} = \frac{9 \text{ mA}}{1 \text{ mA}} = 9$$

41. (d) : During positive half cycle, p-n junction conducts.

$\therefore$ Potential difference across C

= Peak voltage of given ac voltage

$$= V_0 = V_{\text{rms}}\sqrt{2} = 220\sqrt{2} \text{ V}$$

42. (b) : The energy gap of 10 eV corresponds to that of an insulator.

43. (c) : The device X is a full wave rectifier.

44. (b) : When p-n junction is forward biased, applied voltage opposes the barrier potential resulting decrease in barrier potential. When p-n junction is reverse biased, applied voltage supports the barrier potential resulting increase in barrier potential. Thus, curve 1 corresponds to reverse bias and curve 3 corresponds to forward bias.

45. (c) : The α and β are related by the relation

$$\beta = \frac{\alpha}{1-\alpha}$$

For $\alpha = \frac{20}{21}$

$$\beta = \frac{\frac{20}{21}}{1-\frac{20}{21}} = \frac{\frac{20}{21}}{\frac{1}{21}} = 20$$

For $\alpha = \frac{100}{101}$,

$$\beta = \frac{\frac{100}{101}}{1-\frac{100}{101}} = \frac{\frac{100}{101}}{\frac{1}{101}} = 100$$

Thus the value of β lies between 20-100.

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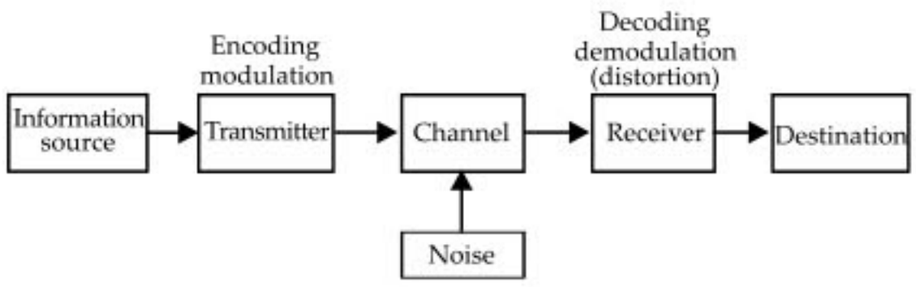
Communication Systems

Communication System

The set up used for exchanging information between a sender and receiver is called communication system.



Block diagram of communication system

A communication system is composed of three basic units.

- Transmitter
- Transmission channel
- Receiver

Transmitter : The part of communication system, which sends out the information is called transmitter.

Transmission channel : The medium or the link, which transfer message signal from the transmitter to the receiver of communication channel.

Receiver : The part of the communication system, which pick up the information sent out by the transmitter is called receiver.

SIGNAL

A processed information converted into electrical pulse for transmission is called a signal.

There are two forms of signal

- Analog signal
- Digital signal

Analog signal : A signal, which is a continuous function of time. In an analog signal, current or voltage value varies continuously with time.

Digital signal : A signal, which is a discontinuous function of time, which has only two levels (either low or high) is called a digital signal.

Transducer : A device which converts energy in one form to another is called a transducer.

Bandwidth of signals

The frequency range of a signal is called its bandwidth. Different types of signals require different ranges of frequencies for proper communication.

These ranges of frequencies are called bandwidths of the corresponding signals.

- Speech signals – Bandwidth is 2800 Hz. (from 300 Hz to 3100 Hz)
- For music – Bandwidth is 20 kHz.
- Video signals – Bandwidth is about 4.2 MHz.

Bandwidth of Transmission Medium

For co-axial cable, bandwidth offered is 750 MHz, (Normally operated below 18 GHz)

For free space communication,

- Standard AM broadcast (~ 540-1600 kHz)
- FM broadcast (~ 88-108 MHz)
- Television (~ 54-890 MHz)
- Satellite communication
  (5.925-6.425 GHz for Uplink)
  (3.7-4.2 GHz for Downlink)

Modulation

Modulation process is used for transmission of signal from transmitter to receiver. In modulation, a high frequency carrier wave is used to carry the information signal. The process of changing some characteristics e.g. amplitude, frequency or phase of carrier wave in accordance with instantaneous value of modulating signal is known as modulation.

Need of Modulation

The sound waves within the range of human hearing have frequency range from 20 Hz to 20 kHz. The sound waves cannot be transmitted from a radio transmitter by converting them into electrical waves (audio signal) directly for the following reasons;

- For efficient transmission and reception, the transmitting and receiving antenna must have a length equal to quarter wavelength of the audio signal. For a frequency of 15 kHz of audio signal, the length of the antenna comes out to be of the order of 5000 m. To set up a vertical antenna of this size is practically impossible.
- The energy radiated from an antenna is practically zero, when the frequency of the signal to be transmitted is below 15 kHz. It also makes the direct transmission of audio signal as impracticable.

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- Due to the fact that all audio signals from different sources possess frequencies in the same range i.e., 20 Hz to 20 kHz, an audio signal cannot be transmitted directly. It is because, the audio signal from different transmitting stations will get hopelessly and inseparably mixed up.

The aforementioned difficulties faced during the transmission of audio signal, if transmitted directly, are overcome by the process of modulation.

The following are three types of modulation.

- Amplitude modulation
- Frequency modulation
- Phase modulation

Amplitude Modulation

In amplitude modulation the amplitude of carrier wave is varied in accordance with the amplitude of the audio frequency modulating signal.

The frequency of amplitude modulated wave remains unchanged as that of the carrier wave.

If modulating signal $m(t) = A_m \sin\omega_m t$ ... (i)

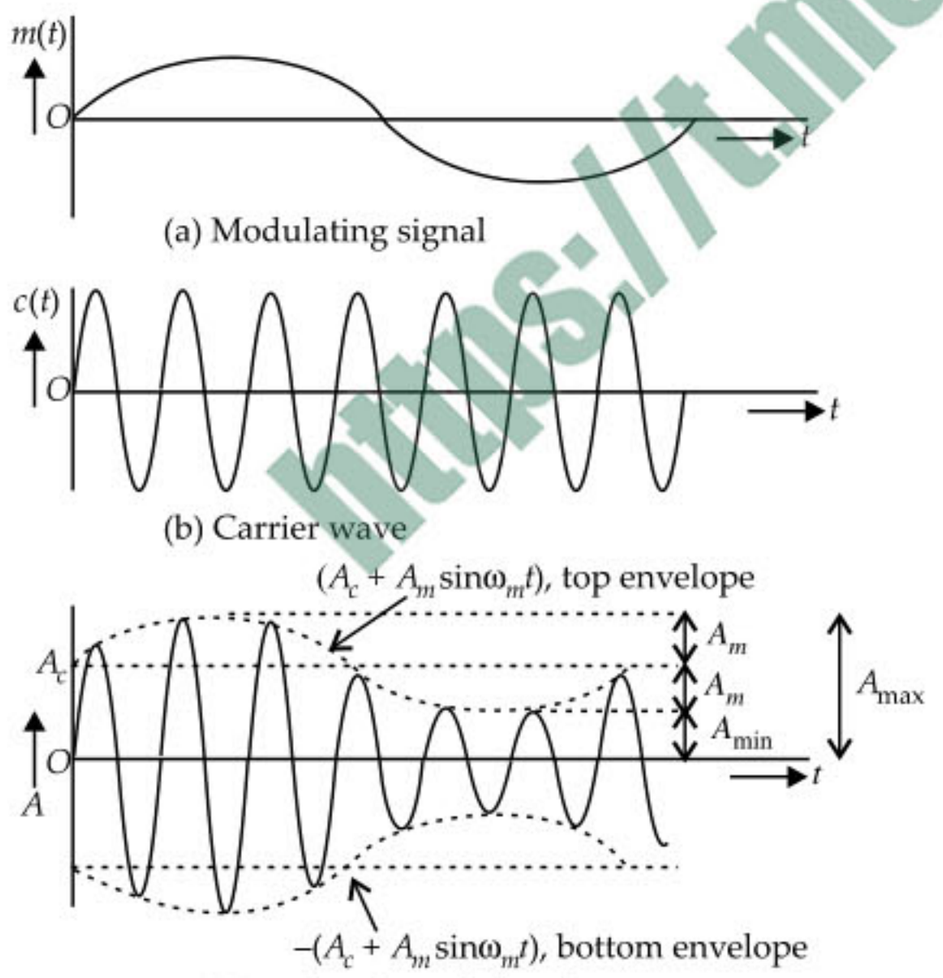
and carrier wave $c(t) = A_c \sin\omega_c t$ ... (ii)

Where ω_c = angular frequency of carrier wave.

ω_m = angular frequency of modulating signal.

A_m, A_c = Peak amplitudes of modulating and carrier waves respectively.

$\mu = \frac{A_m}{A_c}$ (amplitude modulation index), $\mu \leq 1$ or else distortion occurs.



(c) Amplitude modulated wave

The amplitude modulated signal given by

$$c_m(t) = A_c \sin\omega_c t + \mu\frac{A_c}{2}\cos(\omega_c - \omega_m)t - \frac{\mu A_c}{2}\cos(\omega_c + \omega_m)t$$

This modulated wave contains frequencies $(\omega_c - \omega_m)$, ω_c and $(\omega_c + \omega_m)$.

$\omega_c - \omega_m$ and $\omega_c + \omega_m$ are called the lower side band and upper side band frequencies respectively.

In amplitude modulation (AM):

- Index of AM, $\mu = \frac{A_m}{A_c} = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$

  A_c = Peak amplitude of high frequency carrier wave.

  A_m = Peak amplitude of low frequency modulating signal.

- Required band width $= (\omega_c + \omega_m) - (\omega_c - \omega_m)$
  $= 2\omega_m$
- Average power per cycle in the carrier wave is

  $P_c = \frac{A_c^2}{2R}$

  A_c = amplitude of high frequency carrier wave.

  R = load resistance of the circuit.
- It can be shown that total power per cycle in the modulated wave,

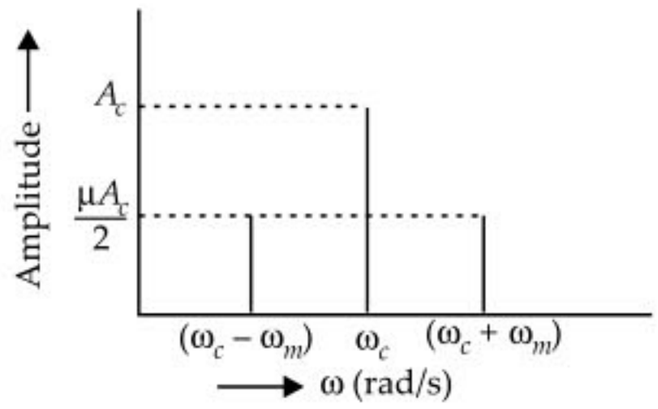
  $P_t = P_c\left(1 + \frac{\mu^2}{2}\right)$
- If I_t is rms value of total modulated current and I_c is the rms value of unmodulated carrier current, then

  $\frac{I_t}{I_c} = \sqrt{1 + \frac{\mu^2}{2}}$
- For detection of AM wave, essential condition is

  $\frac{1}{f_c} << RC$

  where RC = time constant of the circuit.

The amplitude modulated signal contains d.c component and also some different frequencies which are not required. This signal is made to pass through a band pass filter which rejects the d.c. components and also low and high frequencies. It allows a band of frequencies $\omega_c - \omega_m$, ω_c, $\omega_c + \omega_m$ to pass through.



The frequency spectrum of amplitude modulated wave is shown in above figure. The two side band frequencies have equal amplitude $(= \mu A_c/2)$ which never exceeds half the carrier amplitude. $(\therefore \mu = 1)$.

The amplitude modulation index (μ) define the quality of the transmitted signal. When modulation index (μ) is small, variation in carrier amplitude will not be large, therefore, audio signal being transmitted will not be strong.

As the modulation index (μ) increases, the audio signal on reception becomes more clear.

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Frequency Modulation

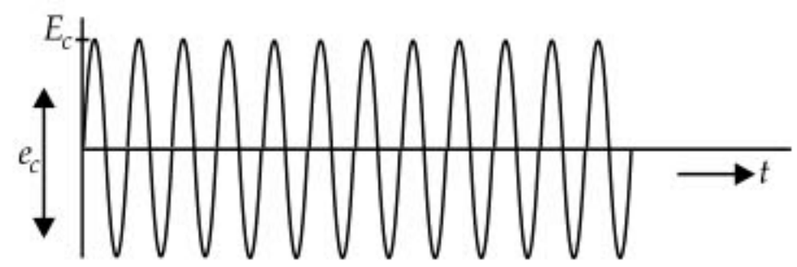
In frequency modulation, the frequency of carrier wave is varied in accordance with the instantaneous value of the modulating voltage.

The instantaneous values of the voltage of carrier waves and modulating signal can be represented as

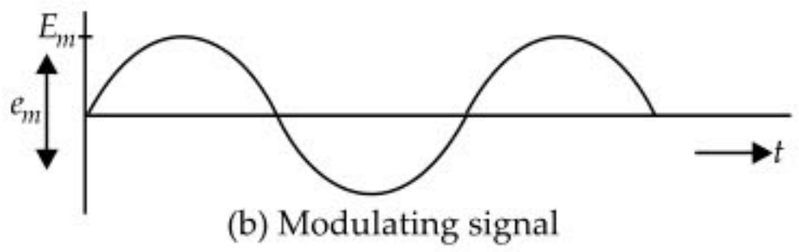
$$e_c = E_c \cos\omega_c t \quad \text{... (i)}$$

and $$e_m = E_m \cos\omega_m t \quad \text{... (ii)}$$

where e_c, E_c, ω_c are the instantaneous value, peak value, angular frequency of the carrier wave and e_m, E_m and ω_m are the instantaneous value, peak value and the angular frequency of the modulating signal.

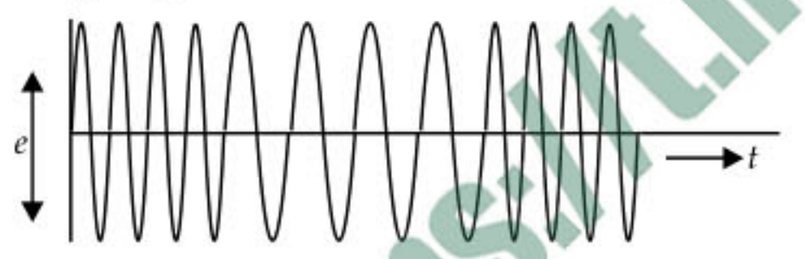


(a) Carrier wave



(b) Modulating signal

Frequency of the carrier signal is varied in accordance with the amplitude of the modulating signal, so that the amplitude of the modulated wave is same as that of the carrier waves. Instantaneous value of modulating signal can be given by $e = E_c \sin\theta$, θ is some function of carrier and modulating frequencies.



(c) Frequency modulating signal

The frequency of modulated signal varies between

$$f_{\min}\left(= f_c - \frac{k_f E_m}{2\pi}\right) \text{ and } f_{\max}\left(= f_c + \frac{k_f E_m}{2\pi}\right)$$

where k_f is the proportionality constant and determines the maximum variation in frequency of modulated wave for a given modulating signal.

The maximum swing of frequency of modulated wave from the carrier frequency is called **frequency deviation (δ).**

$$\delta = f_{\max} - f_c = f_c - f_{\min}$$

The modulation index (m_f) of the frequency modulating wave is

$$m_f = \frac{\delta}{f_m} = \frac{f_{\max} - f_c}{f_m} = \frac{f_c - f_{\min}}{f_m}$$

Bandwidth of FM : In frequency modulated signal, the audio signal is contained in the sidebands. Since the sidebands are separated from each other by the frequency of modulating signal (f_m), bandwidth = $2n$ × frequency of modulating signal where n is the number of significant sidebands pairs.

Advantages of frequency modulation : The following are a few advantages of frequency modulation over amplitude modulation.

- FM reception is quite immune to noise as compared to AM reception. Noise is a form of amplitude variations in the transmitted signal due to atmosphere, industries, etc. In FM receivers, the noise can be reduced by increasing the frequency deviation or by making use of amplitude limiters.
- FM transmission is highly efficient as compared to AM transmission.
- In FM transmission, all the transmitted power is useful; whereas in AM transmission, most of the power goes waste in the transmitted carrier, which contains no useful information.
- Due to a large number of sidebands, FM transmission can be used for the stereo sound transmission.

Disadvantages : The following are a few disadvantages of FM transmission:

- The bandwidth in FM transmission is about 10 times as large as that needed in AM transmission. As a result, much wider frequency channel is required in FM transmission.
- FM reception is limited to line-of-sight. Due to this, area of reception for FM is much smaller than that for AM.
- FM transmitting and receiving equipments are very complex as compared to those employed in AM transmission.

Demodulation

The process of detection or demodulation is the inverse process of modulation. In the process of demodulation, audio signal is separated from the modulated signal.

Modem and Fax

Modem is contraction of the term modulator and demodulation. A modem acts as a modulator in transmitting mode and as a demodulator in receiving mode.

The electronic transmission of a document at a distant place via telephone line is known as facsimilie or FAX.

Earth's Atmosphere

The gaseous envelope surrounding the earth is called earth's atmosphere.

Earth's atmosphere mainly consists of nitrogen 78%, oxygen 21% along with a littile portion of argon, carbon dioxide, water vapour, hydrocarbons, sulphur compounds and dust particles.

Earth's atmosphere helps in the propagation of electromagnetic waves from one place to another place.

The various regions of earth's atmosphere are as follows:

- **Troposphere** : It extends upto a height of 10 km, over earth's surface.

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- **Stratosphere** : It extends from 10 km to 50 km. There is an ozone layer in stratosphere which mostly absorbs high energy radiations like ultraviolet radiations etc. coming from outer space.
- **Mesosphere** : It extends from 50 km to 65 km.
- **Ionosphere** : It extends from 65 km to 400 km. In this region, the temperature rises to some extent with height, hence it is called thermosphere. The ionosphere which is composed of ionised matter (*i.e.*, electrons and positive ions) plays an important role in space communication. The ionosphere is subdivided into four main layers as D, E, F_1 and F_2 as shown in the table.

Name of the layer	Approximate height over earth's surface	Exists during	Frequencies most affected
D	65-75 km	Day only	Reflects LF, absorbs MF and HF to some degree
E	100 km	Day only	Helps surface waves, reflects HF
F_1	170-190 km	Day time, merges with F_2 at night	Partially absorbs HF waves yet allowing them to reach F_2.
F_2	300 km at night, 250-400 km during day time	Day and night	Efficiently reflects HF waves, particularly at night

Radio Waves

The electromagnetic waves of frequency ranging from a few kilohertz to few hundred megahertz are called radio waves.

Frequency range and wavelength range of radiowaves are given in the table.

S. No.	Frequency band	Frequency range	Wavelength range	Main use
1	Very low frequency (VLF)	3 kHz to 30 kHz	10 km to 100 km	Long distance point to point communication
2	Low frequency (LF)	30 kHz to 300 kHz	1 km to 10 km	Marine and navigational purpose
3	Medium frequency (MF)	300 kHz to 3 MHz	100 m to 1 km	Marine and broadcasting purposes
4	High frequency (HF)	3 MHz to 30 MHz	10 m to 100 m	Communications of all types
5	Very high frequency (VHF)	30 MHz to 300 MHz	1 m to 10 m	T.V., Radar and air navigation
6	Ultra high frequency (UHF)	300 MHz to 3000 MHz	10 cm to 1 m	Radar and microwave communication
7	Super high frequency (SHF)	3 GHz to 30 GHz	1 cm to 10 cm	Radar, radio relays and navigation purposes
8	Extremely high frequency (EHF)	30 GHz to 300 GHz	1 mm to 1 cm	Optical fibre communication

Space Communication

The term space communication refers to sending receiving and processing of information through space. There are three types of space communication :

- Ground wave propagation
- Sky wave propagation
- Space wave propagation

Ground Wave Propagation

This mode of propagation can exist when the transmitting and receiving antenna are close to the surface of the earth. For radiating high efficiency signals, the size of the antenna should be of the order of $\lambda/4$. λ = wavelength of the signal.

The field component of such a launched wave soon becomes vertically polarised as it glides over the surface of the earth. The electrical fields due to the wave induce charges in the earth's surface, which travel along with the wave. The ground wave is weakened as a result of energy absorbed by the earth during its propagation. These losses make ground waves unsuitable for very long range communication.

Ground wave propagation can be sustained only at low frequencies (~ 500 kHz to 1500 kHz) or for radio broadcast at long wavelengths.

The ground wave propagation is generally used for local band broadcasting and is commonly called medium wave. The maximum range of ground or surface wave propagation depends on :

- Frequency of the radio waves
- Power of the transmitter

Sky Wave Propagation (Ionospheric Propogation)

A transmitted wave going up is reflected back by the ionosphere which forms an ionised layer of electrons and ions around the earth. The ionosphere (including

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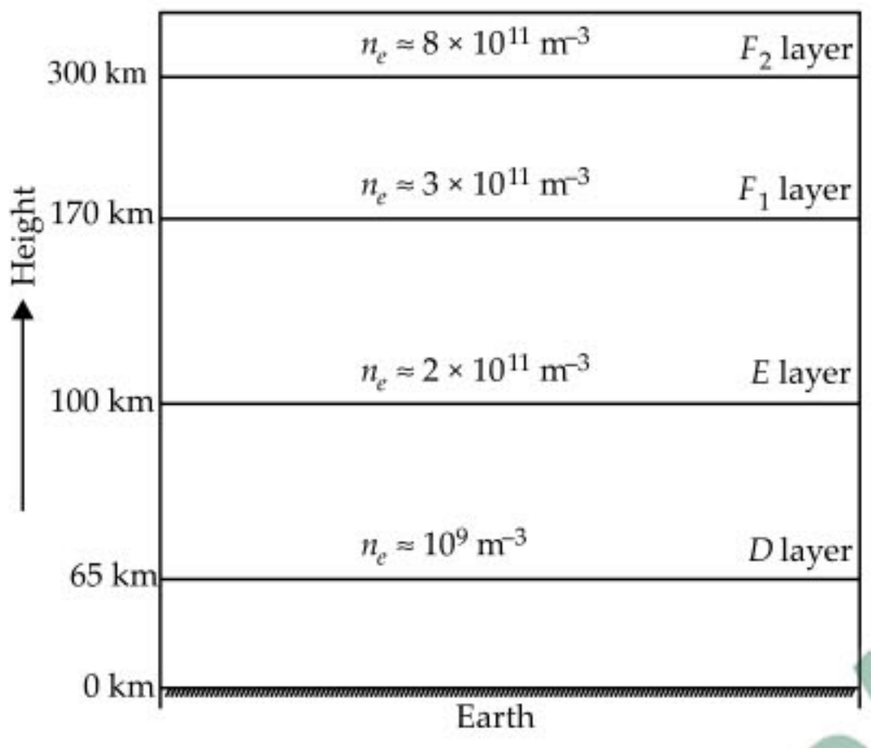
mesosphere and part of stratosphere) extends from about 65 km to 400 km above the earth's surface. Constituent gases are ionised in it by solar radiation. Throughout the ionosphere, there are several layers in which the ionisation density either reaches a maximum or remains roughly constant. These regions are designated as *D*(65-75 km), *E*(100 km) and *F*(130 km-400 km) in order of approximate heights above earth's surface.

During day time the *F* layer splits into separate layers called F_1 (170-190 km over earth's surface) and F_2 (250-400 km over earth's surface). During night F_1 layer usually disappears.



Region of high conductivity is confined to a relatively thin layer at the lower edge of *E*-region and to the upper part of *D*-region. Therefore high frequencies are attenuated when they penetrate this region. *D* and *E* layer disappears during night and low and medium frequency communication also becomes possible.

Ionisation density increases as we go up from *D* layer to *F* layer and then decreases, due to which their respective refractive indices vary. Therefore the transmitted wave is reflected back in a way similar to the phenomenon of total internal refraction.

where

$$\mu' = \mu_0 \left[1 - \left(\frac{Ne^2}{\varepsilon_0 m\omega^2}\right)\right]^{1/2}$$

μ' = refractive index of particular region of ionosphere, m is the mass of the electron, N is the electron density in the ionosphere, ε_0 and n_0 are permittivity and refractive index respectively for free space, e = electronic charge.

Ionosphere behaves as a rarer medium by which carrier wave is reflected back if its frequency ($f \le f_c$) where f_c = critical frequency.

$$f_c \approx 9\,(N_{max})^{1/2}$$

N_{max} = maximum electron density of the ionosphere. f_c is called critical frequency and it represents the highest frequency that will be reflected back from a particular layer at vertical incidence.

Maximum usable frequency (MUF) : It is the highest frequency that can be reflected from a particular layer of ionosphere for a given angle of incidence (i) is given as MUF = $f_c \sec i$.

Space Wave Propagation (Tropospherical Propagation)

This mode is also known as line of sight communication. To send signals at far away stations, either repeater transmitting stations are necessary or height of the transmitter is increased by locating it in a satellite. If h_T is the height of transmitting antenna and d_T is the distance to the horizon from it, then $d_T = \sqrt{2Rh_T}$, where R is the radius of the earth. d_T is called radio horizon of transmitting antenna.

The maximum line-of-sight distance d_M between the two antennas having heights h_T and h_R above the earth is given by

$$d_M = \sqrt{2Rh_T} + \sqrt{2Rh_R}$$

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EXAM DRILL

1. If the maximum amplitude of an amplitude modulated wave is 25 V and the minimum amplitude is 5 V, the modulation index is

(a) $\frac{1}{5}$ (b) $\frac{1}{3}$

(c) $\frac{3}{2}$ (d) $\frac{2}{3}$

2. A signal wave of frequency 12 kHz is modulated with a carrier wave of frequency 2.51 MHz. The upper and lower side band frequencies are respectively

(a) 2512 kHz and 2508 kHz
(b) 2522 kHz and 2488 kHz
(c) 2502 kHz and 2498 kHz
(d) 2522 kHz and 2498 kHz

3. The frequency band used in the downlink of satellite communication is

(a) 9.5 to 2.5 GHz
(b) 896 to 901 MHz
(c) 3.7 to 4.2 GHz
(d) 840 to 935 MHz

4. A basic communication system consists of

(A) transmitter
(B) information source
(C) user of information
(D) channel
(E) receiver

Choose the correct sequence in which these are arranged in a basic communication system.

(a) ABCDE (b) BADEC
(c) BDACE (d) BEADC

5. 1000 kHz carrier wave is amplitude modulated by the signal frequency 200 – 4000 Hz. The channel width of this case is

(a) 8 kHz (b) 4 kHz
(c) 7.6 kHz (d) 3.8 kHz

6. An example of point to point mode of communication is

(a) FM radio
(b) standard FM radio
(c) television
(d) telephony

7. If both the length of an antenna and the wavelength of the signal to be transmitted are doubled, the power radiated by the antenna

(a) is doubled
(b) is halved
(c) remains constant
(d) is quadrupled

8. Identify the incorrect statement from the following.

(a) AM detection is carried out using a rectifer and an envelope detector.
(b) Pulse position denotes the time of rise or fall of the pulse amplitude.
(c) Modulation index μ is kept ≥ 1, to avoid distortion.
(d) Facsimile (FAX) scans the contents of the document to create electronic signals.

9. Through which mode of propagation, the radio waves can be sent from one place to another

(a) ground wave propagation
(b) sky wave propagation
(c) space wave propagation
(d) all of them

10. A television tower of height 140 m can broadcast its signal upto a maximum area of (Radius of earth = 6.4×10^6 m)

(a) 1.56×10^6 km^2 (b) 5.6×10^3 km^2
(c) 5.6×10^{10} km^2 (d) 1.56×10^9 km^2

11. What would be the percentage power saving when the carrier and one of the side bands were suppressed in an AM wave modulated to a depth of 75%?

(a) 89.1% (b) 9.1%
(c) 7.81% (d) 100%

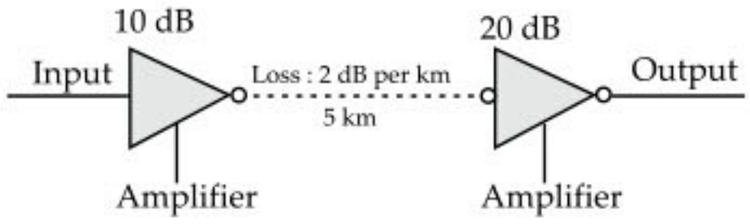
12. A ground receiver station is receiving a signal at 5 MHz, transmitted from a ground transmitter at a height of 300 m located at a distance of 100 km. Identify the mode of propagation. (Radius of earth = 6.4×10^6 m; N_{max} of ionosphere = 10^{12} m^{-3})

(a) ground wave propagation
(b) space wave propagation
(c) sky wave propagation
(d) satellite communication

13. A transmitting antenna at the top of a tower has a height of 36 m and the height of the receiving antenna is 49 m. What is the maximum distance between them for satisfactory communication in LOS mode? (Radius of Earth = 6400 km).

(a) 20 km (b) 25.6 km
(c) 46.5 km (d) 68.4 km

14. Figure shows a communication system. What is the output power when input signal is of 1.01 mW? [Gain in dB = $10 \log_{10} (P_0/P_i)$]



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(a) 90 mW (b) 202 mW
(c) 101 mW (d) 405 mW

15. A sky wave with a frequency 55 MHz is incident on the *D* region of Earth's atmosphere at 30°. The angle of refraction is (electron density for *D*-region is 400×10^6 electrons per m^3)
(a) 60° (b) 15°
(c) 45° (d) 30°

16. A TV tower has a height of 100 m. What is the maximum distance upto which the TV transmission can be received ($R = 8 \times 10^6$ m)?
(a) 34.77 km (b) 32.70 km
(c) 40 km (d) 40.70 km

17. Which of the following is not a transducer?
(a) Microphone
(b) Loudspeaker
(c) Earphone
(d) Amplifier

18. If the maximum amplitude of an amplitude modulated wave is 20 V and the minimum amplitude is 4 V, then the modulation index is
(a) $\frac{1}{3}$ (b) $\frac{3}{2}$
(c) $\frac{2}{3}$ (d) $\frac{1}{5}$

19. Which of the following statements is correct?
(a) Pulse position denotes the time of rise or fall of the pulse amplitude.
(b) Modulation index μ is kept ≥ 1 to avoid distortion.
(c) The audible range of frequencies is 20 Hz to 200 MHz.
(d) In amplitude modulation, the bandwidth is thrice the modulating frequency.

20. AM is used for broadcasting because
(a) it requires less transmitting power compared with other systems
(b) it is more noise immune than other modulation systems
(c) its use avoids receiver complexity
(d) no other modulation system can provide the necessary bandwidth faithful transmission.

21. A transmitting antenna of height 20 m and the receiving antenna of height *h* are separated by a distance of 40 km for satisfactory communication in line-of-sight mode. Then the value of *h* is (Radius of the earth is 6400 km)
(a) 20 m (b) 40 m
(c) 45 m (d) 50 m

22. Which of the following would produce analog signals?
(1) Light pulse.
(2) Musical sound due to a vibrating sitar string.
(3) Output of a NOR gate.
(4) A vibrating tuning fork.
(a) 1 and 3 (b) 2 and 4
(c) 1, 2 and 3 (d) All

23. Identify the correct match from the following.
(a) Half duplex device – Mobile phone
(b) Full duplex device – Modulator and demodulator
(c) Modem – Walky talky
(d) Fax – Transmission and reproduction of documents at a distant place

24. A message signal of frequency 10 kHz and peak voltage of 10 V is used to modulate a carrier of frequency 1 MHz and peak voltage of 20 V. Then the modulation index and the side band frequencies respectively are
(a) 0.05 and (1 ± 0.01) MHz
(b) 0.5 and (1 ± 0.01) MHz
(c) 0.05 and (1 ± 0.005) MHz
(d) 0.5 and (1 ± 0.005) MHz

25. A diode AM detector with the output circuit consisting of $R = 1$ MΩ and $C = 1$ pF would be more suitable for detecting a carrier signal of
(a) 0.1 MHz (b) 0.5 MHz
(c) 1 MHz (d) 10 MHz

26. Of the following which is preferred modulation scheme for digital communication?
(a) Pulse Amplitude Modulation (PAM)
(b) Pulse Position Modulation (PPM)
(c) Pulse Width Modulation (PWM)
(d) Pulse Code Modulation (PCM)

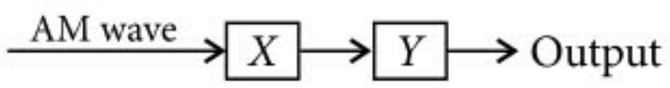
27. Match the List I with List II and select the correct answer using the codes given below the lists.

List I (Name of service)		List II (Frequency band)	
P.	AM broadcast	1.	3.7-4.2 GHz
Q.	FM broadcast	2.	420-890 MHz
R.	UHF TV	3.	88-108 MHz
S.	Downlink of satellite communication	4.	540-1600 kHz

Codes:

	P	Q	R	S
(a)	3	4	1	2
(b)	4	3	2	1
(c)	2	1	3	4
(d)	1	2	4	3

28. The block diagram of a detector for AM signal is as shown in the figure. Identify the boxes *X* and *Y*.



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	X	Y
(a)	Amplifier	Rectifier
(b)	Envelope detector	Rectifier
(c)	Rectifier	Envelope detector
(d)	Rectifier	Amplifier

29. In TV broadcasting both picture and sound are transmitted simultaneously. In this
(a) audio signal is frequency modulated and video signal is amplitude modulated
(b) both audio and video signals are frequency modulated
(c) audio signal is amplitude modulated and video signal is frequency modulated
(d) both audio and video signals are amplitude modulated.

30. Which of the following waves are used for satellite communication?
(a) Ground (b) Space
(c) Sound (d) Sky

31. Which of the following is an example of point-to-point mode of communication?
(a) Internet (b) Radio
(c) Telephony (d) TV

32. In an amplitude modulated wave for audio frequency of 1000 Hz, the appropriate carrier frequency will be
(a) 10 Hz (b) 100 Hz
(c) 1 kHz (d) 1 MHz

33. A 1000 kHz carrier wave is modulated by an audio signal of frequency range 500-5000 Hz. Then the bandwidth of the channel is
(a) 10 kHz (b) 20 kHz
(c) 25 kHz (d) 50 kHz

34. The sky wave propagation is suitable for radiowaves of frequency
(a) upto 3 MHz
(b) from 3 MHz to 20 MHz
(c) from 3 MHz to 30 MHz
(d) from 3 MHz to 50 MHz

35. In the daytime, ionosphere consists of
(a) D, E, and F_1 layers only
(b) E, F_1 and F_2 layers only
(c) E and F_2 layers only
(d) D, E, F_1 and F_2 layers

36. How many AM broadcast stations can be accommodated in a 100 kHz bandwidth if the highest frequency modulating a carrier is 5 kHz?
(a) 5 (b) 10
(c) 15 (d) 20

37. A radiostation has two channels. One is AM at 1020 kHz and the other FM at 89.5 MHz. For good results you will use
(a) longer antenna for the AM channel and shorter for the FM.
(b) shorter antenna for the AM channel and longer for the FM.
(c) same length antenna will work for both.
(d) information given is not enough to say which one to use for which.

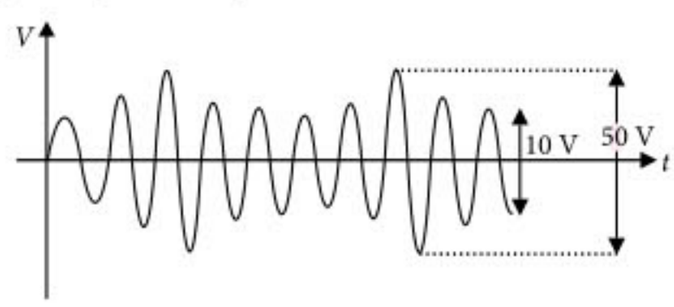
38. What should be the length of the dipole antenna for a carrier wave of frequency 300 MHz?
(a) 0.5 m (b) 1 m
(c) 1.5 m (d) 2 m

39. A message signal of angular frequency ω_m is superposed on a carrier wave of angular frequency ω_c to get an amplitude modulated wave (AM). The angular frequency of the AM wave will be
(a) ω_m (b) ω_c
(c) $\frac{\omega_c + \omega_m}{2}$ (d) $\frac{\omega_c - \omega_m}{2}$

40. The radiating power of a linear antenna of radiating length l for a wavelength λ is proportional to
(a) $\frac{l}{\lambda}$ (b) $\frac{l^2}{\lambda^2}$
(c) $\frac{l}{\lambda^2}$ (d) $\frac{l^2}{\lambda}$

41. A ground receiver station is receiving a signal at 5 MHz and transmitted from a ground transmitter at a height of 300 m located at a distance of 100 km. The signal is coming via
(Radius of earth = 6.4×10^6 m,
N_{max} of ionosphere = 10^{12} m^{-3})
(a) sky wave
(b) space wave
(c) satellite communication
(d) all of these

42. An amplitude modulated wave is as shown in figure. The value of peak carrier voltage and peak information voltage respectively are



(a) 25 V, 15 V (b) 10 V, 15 V
(c) 15 V, 10 V (d) 25 V, 5 V

43. A radar has a power of 1 kW and is operating at a frequency of 10 GHz. It is located on a mountain top of height 500 m. The maximum distance upto which it can detect object located on the surface of the earth is
(Radius of earth = 6.4×10^6 m)

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(a) 80 km (b) 16 km
(c) 40 km (d) 64 km

44. An AM radio station operating at 530 kHz is permitted to broadcast audio frequencies upto 5 kHz. The band pass filter in its modulation circuit can retain the frequencies
(a) 1060 kHz, 530 kHz
(b) 535 kHz, 530 kHz
(c) 5 kHz, 530 kHz
(d) 10 kHz, 5 kHz

45. A 300 W carrier is modulated to a depth 75%. The total power in the modulated wave is
(a) 200 W (b) 284 W
(c) 320 W (d) 384 W

DAY 29 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ◉

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____
(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

1. **(d) :** Maximum amplitude, $A_{max} = A_c + A_m$ ...(i)
Minimum amplitude, $A_{min} = A_c - A_m$ ...(ii)
Solving (i) and (ii), we get

$$A_c = \frac{A_{max} + A_{min}}{2}, \quad A_m = \frac{A_{max} - A_{min}}{2}$$

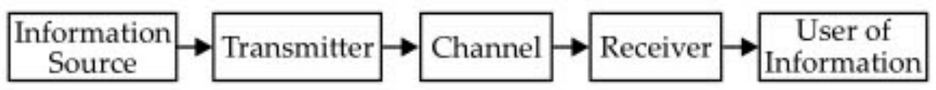
Modulation index, $\mu = \frac{A_m}{A_c} = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$

$$\mu = \frac{25\text{ V} - 5\text{ V}}{25\text{ V} + 5\text{ V}} = \frac{20}{30} = \frac{2}{3}$$

2. **(d) :** Here, $\upsilon_s = 12$ kHz, $\upsilon_c = 2.51$ MHz $= 2510$ kHz. The upperside band frequency $= \upsilon_c + \upsilon_s$
$= (2510 + 12)$ kHz $= 2522$ kHz
The lower side band frequency $= \upsilon_c - \upsilon_s$
$= (2510 - 12)$ kHz $= 2498$ kHz

3. **(c) :** The frequency band used in the downlink of satellite communication is 3.7 to 4.2 GHz.

4. **(b) :** The block diagram of a communication system is shown in the figure below.



5. **(a) :** Bandwidth is equal to twice the frequency of modulating signals.
Therefore,
Band width $= 2\upsilon_m$
$= 2 \times 4000$ Hz $= 8 \times 10^3$ Hz $= 8$ kHz

6. **(d) :** In point-to-point communication mode, communication takes place over a link between a single transmitter and a receiver. Telephony is an example of such a mode of communication.

7. **(c) :** Power radiated by the antenna is proportional to $\left(\frac{l}{\lambda}\right)^2$. When both the length of the antenna l and wavelength of the signal λ are doubled, the power radiated by the antenna remains constant.

8. **(c) :** Modulation index μ is kept ≤ 1 to avoid distortion.

9. **(d)**

10. **(b) :** Here, $h = 140$ m
$R = 6.4 \times 10^6$ m
Coverage range, $d = \sqrt{2Rh}$
Area covered $= \pi d^2 = \pi 2Rh$

$$= \frac{22}{7} \times 2 \times 6.4 \times 10^6 \times 140$$

$= 5632 \times 10^6$ m$^2 = 5.6 \times 10^9$ m^2
$= 5.6 \times 10^3$ km^2

11. **(a) :** Here, modulation index, $\mu = \frac{75}{100} = \frac{3}{4}$,
Power produced by the AM transmitter

$$\text{As} \quad P_t = P_c\left(1 + \frac{\mu^2}{2}\right) = P_c\left(1 + \frac{9}{32}\right) = P_c \times \frac{41}{32}$$

$$P_{SB} = P_c \frac{\mu^2}{4} = P_c \times \frac{9}{16 \times 4} = \frac{9}{64} P_c$$

On suppressing, power saved is

$$= P_c + \frac{9}{64} P_c = \frac{73}{64} P_c$$

$$\therefore \quad \text{Percentage saving} = \frac{\frac{73}{64} P_c}{P_t} \times 100$$

$$= \frac{\frac{73}{64} P_c}{\frac{41}{32} P_c} \times 100 = \frac{73 \times 32}{64 \times 41} \times 100 = 89.1\%$$

12. **(c) :** Maximum distance covered by space wave communication

$$= \sqrt{2Rh_T} = \sqrt{2 \times 6.4 \times 10^6 \times 300} \simeq 62 \times 10^3 \text{ m}$$

Since receiver-transmitter distance is 100 km. Therefore signal cannot go either by ground wave or space wave.
For sky wave, the value of critical frequency of signal should be

$$\upsilon_c = 9(N\max)^{\frac{1}{2}} = 9(10^{12})^{\frac{1}{2}} = 9 \times 10^6 \text{ Hz} = 9 \text{ MHz}$$

As the signal frequency 5 MHz < 9 MHz, so the communication is through sky waves.

13. **(c) :** Here, $h_T = 36$ m, $h_R = 49$ m and $R = 6400$ km
If d_M is the maximum distance between two antennas for satisfactory communication in LOS mode, then

$$d_M = d_T + d_R$$

$$= \sqrt{2Rh_T} + \sqrt{2Rh_R}$$

$$= \sqrt{(2 \times 6400 \text{ km} \times 36 \times 10^{-3} \text{km})} + \sqrt{(2 \times 6400 \text{ km} \times 49 \times 10^{-3} \text{km})}$$

$= 21.5$ km $+ 25$ km $= 46.5$ km

14. **(c) :** Total gain of both the amplifiers
$= 10$ dB $+ 20$ dB $= 30$ dB
Loss suffered in transmission path
$= (2$ dB/km$)(5$ km$) = 10$ dB
overall gain of the signal = net gain of the amplifier
$= 30$ dB $- 10$ dB $= 20$ dB
As gain in dB $= 10\log_{10}(P_0/P_i)$,
$20 = 10\log_{10}(P_0/P_i)$ or $\log_{10}(P_0/P_i) = 2$
or $(P_0/P_i) = 10^2$
or $P_0 = 10^2 P_i = 10^2 \times 1.01$ mW $= 101$ mW

15. **(d) :** Here for D region, $\upsilon = 55 \times 10^6$ Hz, $i = 30°$, $N = 400 \times 10^6$ electrons per m^3

$$\text{As} \quad \mu = \sqrt{1 - \frac{81.45\,N}{\upsilon^2}} = \sqrt{1 - \frac{81.45 \times 400 \times 10^6}{(55 \times 10^6)^2}} \simeq 1$$

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Now $\mu = \frac{\sin i}{\sin r}$ or $\frac{\sin i}{\sin r} = 1$

or $\sin i = \sin r$

$\therefore \quad i = r = 30°$

16. **(c) :** Maximum distance, $d = \sqrt{2hR}$

$= \sqrt{2 \times 100 \times 8 \times 10^6} = 40 \times 10^3 \text{ m} = 40 \text{ km}$

17. **(d) :** Any device that converts one form of energy into another is called a transducer. Loudspeaker, microphone and earphone are transducers but not an amplifier.

18. **(c) :** Let A_c and A_m be the amplitude of carrier wave and message signal respectively. Then

Maximum amplitude, $A_{max} = A_c + A_m$ ... (i)

Minimum amplitude, $A_{min} = A_c - A_m$ ... (ii)

On solving eqns (i) and (ii), we get

$$A_c = \frac{A_{max} + A_{min}}{2} \text{ and } A_m = \frac{A_{max} - A_{min}}{2}$$

Modulation index, $\mu = \frac{A_m}{A_c} = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$

Here, $A_{max} = 20$ V, $A_{min} = 4$ V

$\therefore \quad \mu = \frac{20 \text{ V} - 4 \text{ V}}{20 \text{ V} + 4 \text{ V}} = \frac{16 \text{ V}}{24 \text{ V}} = \frac{2}{3}$

19. **(a) :** Modulation index $\mu \leq 1$ to avoid distortion.

The audible range of frequencies is 20 Hz to 20 kHz.

In amplitude modulation, the bandwidth is twice the modulating frequency.

20. **(c) :** AM is used for broadcasting because its use avoids receiver complexity. Only a diode and a capacitor are sufficient to separate the audio signal from the AM wave.

21. **(c) :** The maximum line-of-sight distance d_M between two antennas having heights h_T and h_R is

$$d_M = \sqrt{2Rh_T} + \sqrt{2Rh_R}$$

where R is the radius of the earth, h_T and h_R are the heights of the transmitting and receiving antennas respectively.

Here, $d_M = 40 \text{ km} = 40 \times 10^3$ m, $h_T = 20$ m,

$h_R = h$, $R = 6400 \text{ km} = 6400 \times 10^3$ m

$\therefore \quad 40 \times 10^3 = \sqrt{2 \times 6400 \times 10^3 \times 20} + \sqrt{2 \times 6400 \times 10^3 \times h}$

$$40 \times 10^3 = 16 \times 10^3 + \sqrt{2 \times 64 \times 10^5 \times h}$$

$$h = \frac{[(40 - 16) \times 10^3]^2}{2 \times 64 \times 10^5} = 45 \text{ m}$$

22. **(b) :** A vibrating tuning fork and musical sound due to a vibrating sitar string produce analog signals. Light pulse and output of a NOR gate produce digital signals.

23. **(d) :** Half duplex device – Walky talky

Full duplex device – Mobile phone

Modem – Modulator and demodulator

Fax – Transmission and reproduction of documents at a distant place

24. **(b) :** Here, $\upsilon_m = 10 \text{ kHz} = 0.01 \text{ MHz}$, $A_m = 10$ V,

$\upsilon_c = 1 \text{ MHz}$, $A_c = 20$ V

Modulation index, $\mu = \frac{A_m}{A_c} = \frac{10 \text{ V}}{20 \text{ V}} = 0.5$

The side band frequencies are

$\upsilon_{SB} = \upsilon_c \pm \upsilon_m = (1 \pm 0.01) \text{ MHz}$

25. **(d) :** Here, $R = 1 \text{ M}\Omega = 10^6 \Omega$

$C = 1 \text{ pF} = 10^{-12}$ F

$\therefore \quad RC = (10^6)(10^{-12}) = 10^{-6}$ s

For demodulation, $\frac{1}{\upsilon_c} << RC$ or $\upsilon_c >> \frac{1}{RC}$

where υ_c is the frequency of the carrier signal.

$\therefore \quad \upsilon_c >> \frac{1}{10^6} = 10^6 \text{ Hz} = 1 \text{ MHz}$

Thus, it would be more suitable for detecting a carrier signal of 10 MHz.

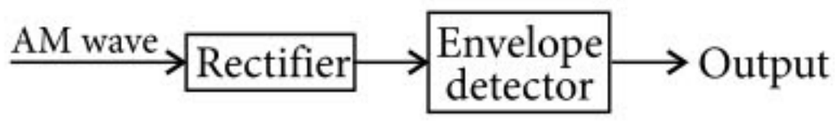
26. **(d) :** The preferred modulation scheme for digital communication is pulse code modulation.

27. **(b) :**

Name of service	Frequency band
AM broadcast	540 - 1600 kHz
FM broadcast	88 - 108 MHz
UHF TV	420 - 890 MHz
Downlink of satellite communication	3.7 - 4.2 GHz

P-4, Q-3, R-2, S-1

28. **(c) :** The block diagram of a detector for AM signal is as shown in the figure.



The box X is a rectifier and the box Y is an envelope detector.

29. **(a) :** In TV broadcasting both AM and FM are used. AM is for video (picture) signal and FM is for audio (sound) signal.

30. **(b) :** Space waves are used for satellite communication.

31. **(c) :** In point-to-point communication mode, communication takes place over a link between a single transmitter and a receiver. Telephony is an example of such a mode of communication.

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32. **(d) :** Carrier frequency > Audio frequency

33. **(a) :** Bandwidth is twice the maximum frequency of modulating signal.

$\therefore$ Bandwidth of the channel = $2(\upsilon_m)_{max}$
= 2 × 5000 Hz = 10000 Hz = 10 kHz

34. **(c) :** The radiowaves of frequency 3 MHz to 30 MHz are used in sky wave propagation as they are reflected by the ionosphere of earth's atmosphere.

35. **(d) :**

Layers of ionosphere	Exists during
D	Day only
E	Day only
F_1	Daytime, merges with F_2 at night
F_2	Day and night

36. **(b) :** Here, total bandwidth = 100 kHz
$= 100 \times 10^3$ Hz
Any station being modulated by a 5 kHz signal will produce an upper side frequency 5 kHz above its carrier and a lower side frequency 5 kHz below its carrier, thereby requiring a bandwidth of 10 kHz. Thus,
Number of stations accommodated

$$= \frac{\text{Total bandwidth}}{\text{Bandwidth per station}} = \frac{100\times10^3 \text{ Hz}}{10\times10^3 \text{ Hz}} = 10$$

37. **(b) :** For the communication of AM channel of frequency 1020 kHz, ground wave propagation is used. For this the antenna need not be very tall.
For the communication of FM channel of frequency 89.5 MHz, the space wave propagation is needed. For this, very tall towers are used as antenna.

38. **(a) :** Here, υ = 300 MHz = 300×10^6 Hz = 3×10^8 Hz
Length of the dipole antenna

$$= \frac{\lambda}{2} = \frac{c}{2\upsilon} = \frac{3\times10^8 \text{ m s}^{-1}}{2\times3\times10^8 \text{ Hz}} = 0.5 \text{ m}$$

39. **(b)**

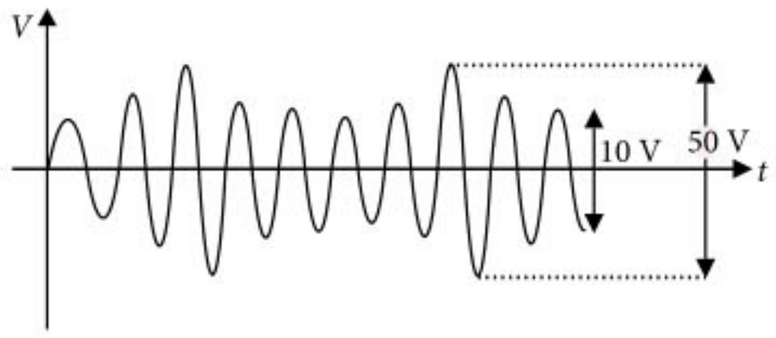
40. **(b) :** Power radiated by the linear antenna is proportional to $(l/\lambda)^2$.

41. **(a) :** Maximum distance covered by space wave communication

$$= \sqrt{2Rh} = \sqrt{2\times6.4\times10^6\times300} = 62 \text{ km}$$

As the distance between transmitter and receiver is 100 km, so propagation via space wave is not possible for the signal of frequency 5 MHz.
For sky wave propagation,
Critical frequency, $\upsilon_c = 9(N_{max})^{1/2} = 9(10^{12})^{1/2}$
$= 9 \times 10^6$ Hz = 9 MHz
As signal of frequency 5 MHz is less than υ_c, so the propagation of signal of frequency 5 MHz is possible via sky wave.

42. **(c) :**



From figure,

$$V_{max} = \frac{50 \text{ V}}{2} = 25 \text{ V}, \; V_{min} = \frac{10 \text{ V}}{2} = 5 \text{ V}$$

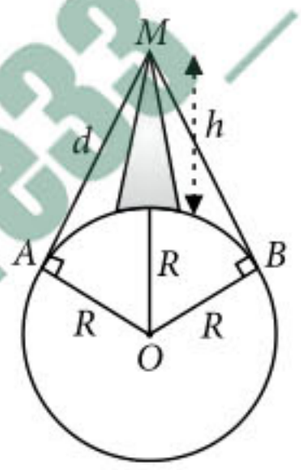
Peak carrier voltage,

$$V_c = \frac{V_{max} + V_{min}}{2} = \frac{25\text{V} + 5\text{V}}{2} = \frac{30\text{V}}{2} = 15\text{V}$$

Peak information voltage,

$$V_m = \frac{V_{max} - V_{min}}{2} = \frac{25\text{V} - 5\text{V}}{2} = \frac{20\text{V}}{2} = 10\text{V}$$

43. **(a) :**



Let M be the mountain top where a radar has been operating to locate the objects on earth.
Let d ($MA = MB$) be the maximum distance of radar from earth where object can be detected.
Refer figure,

$$d^2 + R^2 = (h + R)^2 = h^2 + 2hR + R^2$$

or $d^2 = h^2 + 2hR$
Since $h \ll R$, so h^2 can be neglected in comparison to $2hR$.

$\therefore$ $d^2 = 2hR$ or $d = \sqrt{2hR}$

Here, h = 500 m, $R = 6.4 \times 10^6$ m

$$\therefore \quad d = \sqrt{2\times500\times(6.4\times10^6)} = 80 \times 10^3 \text{ m} = 80 \text{ km}$$

44. **(b) :** The band pass filter retains the frequencies υ_c, $\upsilon_c - \upsilon_m$ and $\upsilon_c + \upsilon_m$ and rejects the frequencies υ_m, $2\upsilon_m$ and $2\upsilon_c$.
Here, υ_c = 530 kHz, υ_m = 5 kHz
$\therefore$ The frequencies retained by the band pass filter are

υ_c = 530 kHz
$\upsilon_c - \upsilon_m$ = (530 – 5) kHz = 525 kHz
$\upsilon_c + \upsilon_m$ = (530 + 5) kHz = 535 kHz

45. **(d) :** P_c = 300 W, μ = 75% = 0.75

As $P_t = P_c\left(1+\frac{\mu^2}{2}\right)$ or $P_t = 300\left(1+\frac{(0.75)^2}{2}\right) = 384$ W

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Unit Test 5

- Dual Nature of Radiation and Matter
- Atoms • Nuclei
- Semiconductor Electronics
- Communication Systems

Unit test is complementary part of the learning process. It gives you a total insight whether the learning outcomes have been achieved or not. After doing daywise preparation, attempt these questions in exam like environment. This will assist you in finding particular area of weakness to work upon. An OMR sheet is given at the end to fill the correct answers.

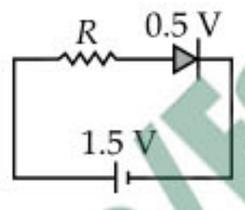
All the Best!

Max. Marks : 180 **Time : 45 min.**

1. The weight based ratio of U^{238} and Pb^{226} in a sample of rock is 4 : 3. If the half life of U^{238} is 4.5×10^9 years, then the age of rock is

(a) 9.0×10^9 years (b) 6.3×10^9 years
(c) 4.5×10^9 years (d) 3.78×10^9 years

2. The diode used in the circuit shown in figure has a constant voltage drop at 0.5 V at all currents and a maximum power rating of 100 mW. What should be the value of the resistor R, connected in series with diode, for obtaining maximum current?



(a) 6.76 Ω
(b) 20 Ω
(c) 5 Ω
(d) 5.6 Ω

3. The wavelength of the first line of Lyman series for hydrogen atom is equal to that of the second line of Balmer series for a hydrogen like ion. The atomic number Z of hydrogen like ion is

(a) 2 (b) 3 (c) 4 (d) 1

4. Light from a hydrogen discharge tube is incident on the cathode of a photoelectric cell. The work function of the cathode surface is 4.2 eV. In order to reduce the photocurrent to zero, the voltage of the anode relative to the cathode must be made

(a) − 4.2 V (b) − 9.4 V (c) − 17.8 V (d) + 9.4 V

5. Excitation energy of a hydrogen like ion in its first excitation state is 40.8 eV. Energy needed to remove the electron from the ion in ground state is

(a) 54.4 eV (b) 13.6 eV (c) 40.8 eV (d) 27.2 eV

6. In a common emitter amplifier, using output resistance of 5000 Ω and input resistance of 2000 Ω, if the peak value of input signal voltage is 10 mV and $\beta = 50$, then peak value of output voltage is

(a) 5×10^{-6} V (b) 12.5×10^{-4} V
(c) 1.25 V (d) 125 V

7. After 280 days, the activity of a radioactive sample is 6000 dps. The activity reduces to 3000 dps after another 140 days. The initial activity of the sample in dps is

(a) 5000 (b) 9000 (c) 3000 (d) 24000

8. One way in which the operation of an n-p-n transistor differs from that of a p-n-p transistor is that

(a) the emitter junction is reverse biased in the n-p-n
(b) the emitter injects minority carriers into the base region of the p-n-p and majority carriers in the base region of the n-p-n
(c) the emitter injects holes into the base region of the p-n-p and electrons into the base region of the n-p-n
(d) the emitter injects electrons into the base region of the p-n-p and holes into the base region of the n-p-n.

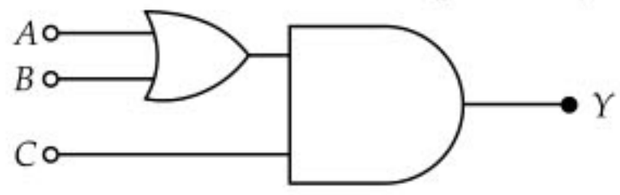
9. The maximum wavelength of radiation that can produce photoelectric effect in certain metal is 200 nm. The maximum kinetic energy acquired by electron due to radiation of wavelength 100 nm will be

(a) 12.4 eV (b) 6.2 eV (c) 100 eV (d) 200 eV

10. When a hydrogen atom emits a photon in going from $n = 5$ to $n = 1$, its recoil speed is almost

(a) 10^{-4} m s^{-1} (b) 8×10^2 m s^{-1}
(c) 2×10^{-2} m s^{-1} (d) 4 m s^{-1}

11. To get an output $Y = 1$ from the circuit shown in figure the inputs A, B and C must be respectively



(a) 1, 0, 1 (b) 1, 1, 0 (c) 0, 1, 0 (d) 1, 0, 0

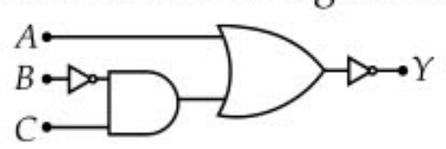
12. Maximum velocity of the photo electrons emitted by a metal surface is 1.2×10^6 m s^{-1}. Assuming the specific charge of the electron to be 1.8×10^{11} C kg^{-1}, the value of the stopping potential in V will be

(a) 2 (b) 3 (c) 4 (d) 6

13. 10^{-3} kg of radioactive isotope of atomic mass 226 emits 3.27×10^{10} α-particles in a second. If 4.2×10^2 J of energy is released in 1 hour in this process, the average energy of the α-particle is

(a) 1.42 MeV (b) 1.96 MeV
(c) 9.02 MeV (d) 19.6 MeV

14. The output Y of the logic circuit shown in figure is best represented as



(a) $\bar{A} + \overline{B \cdot C}$
(b) $A + \bar{B} \cdot C$
(c) $\overline{A + B \cdot C}$ (d) $\overline{A + \bar{B} \cdot C}$

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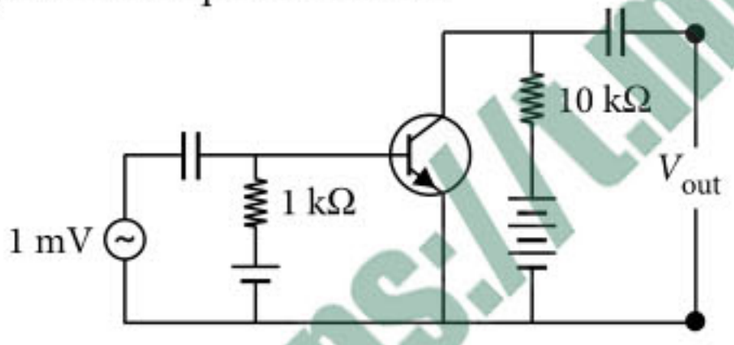
15. The electrical conductivity of a semiconductor increases when electromagnetic radiation of wavelength shorter than 2480 nm is incident on it. The band gap for the semiconductor is
(a) 0.5 eV (b) 1.7 eV (c) 1.1 eV (d) 2.5 eV

16. If the series limit wavelength of the Lyman series for hydrogen atom is 912 Å, then the series limit wavelength of the Balmer series for the hydrogen atom is
(a) 912 Å (b) 912×2 Å
(c) 912×4 Å (d) $\frac{912}{2}$ Å

17. For a common emitter amplifier, the audio frequency voltage across the collector resistance 2 kΩ is 2 V. If the current amplification factor of the transistor is 200, and the base resistance is 1.5 kΩ, the input signal voltage and base current are
(a) 0.1 V and 1 μA (b) 0.15 V and 10 μA
(c) 0.015 V and 1 A (d) 0.0075 V and 5 μA

18. A 12 V battery is applied in forward bias across a circuit having *p*-*n* junction and resistance *R* in series. A 0.6 V potential drop is across *p*-*n* junction and current is 2×10^{-3} A. The resistance *R* is
(a) $5.7 \times 10^2\ \Omega$ (b) $5.7 \times 10^3\ \Omega$
(c) $5.7 \times 10^4\ \Omega$ (d) $5.7 \times 10^5\ \Omega$

19. In the common-emitter configuration, an *n*-*p*-*n* transistor with current gain 100 is used. The output voltage of the amplifier will be

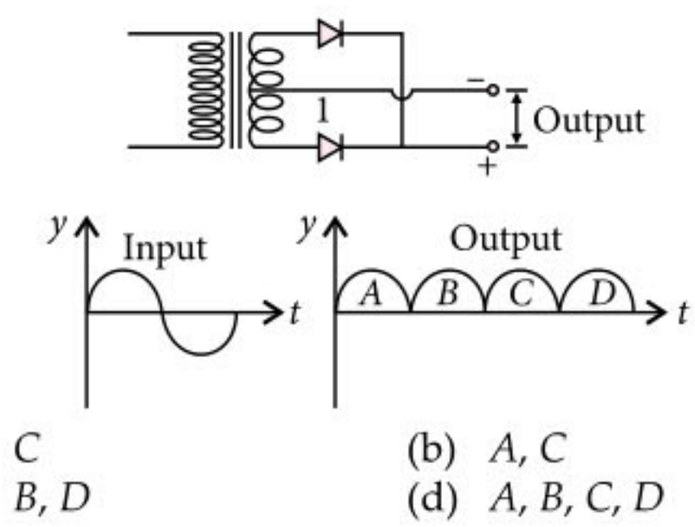


(a) 10 mV (b) 0.1 V (c) 1.0 V (d) 10 V

20. $^{221}_{87}$Ra is a radioactive substance having half-life of 4 days. The probability that a nucleus undergoes decay in two half-lives is
(a) 1 (b) 1/2 (c) 3/4 (d) 1/4

21. An electron of mass *m* with an initial velocity $\vec{v} = v_0 \hat{i}$ is in an electric field $\vec{E} = E_0 \hat{j}$. If $\lambda_0 = h/mv_0$, its de Broglie wavelength at time *t* is given by
(a) λ_0 (b) $\lambda_0 \sqrt{1+\frac{e^2E_0^2t^2}{m^2v_0^2}}$
(c) $\frac{\lambda_0}{\sqrt{1+\frac{e^2E_0^2t^2}{m^2v_0^2}}}$ (d) $\frac{\lambda_0}{\left(1+\frac{e^2E_0^2t^2}{m^2v_0^2}\right)}$

22. A full-wave rectifier circuit along with the output is shown in figure. The contribution (s) from the diode 1 is (are)

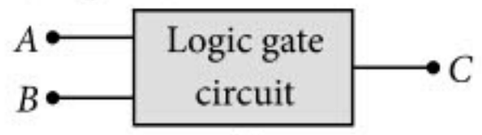


(a) *C* (b) *A*, *C*
(c) *B*, *D* (d) *A*, *B*, *C*, *D*

23. If the wavelength of first line of Balmer series is 6563 Å, the wavelength of first line of Lyman series and Rydberg's constant respectively will be
(a) 1215.4 Å, $1.1 \times 10^7\ m^{-1}$
(b) 5863 Å, $2.0 \times 10^7\ m^{-1}$
(c) 2316.4 Å, $0.1 \times 10^7\ m^{-1}$
(d) none of these

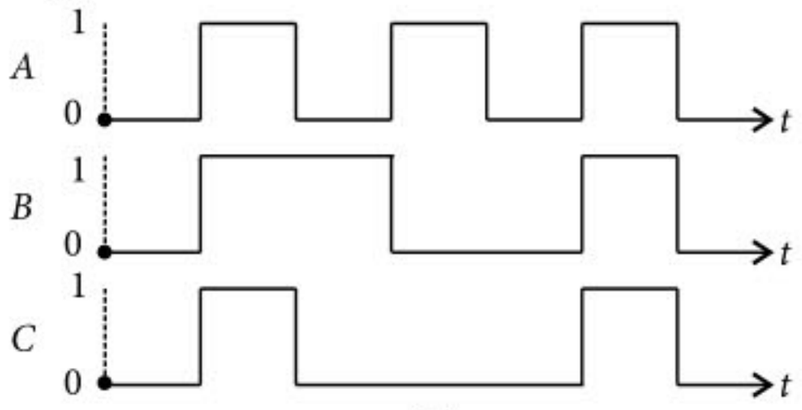
24. In a photoemissive cell, with exciting wavelength λ, the fastest electron has speed *v*. If the exciting wavelength is changed to 3λ/4, the speed of the fastest emitted electron will be
(a) less than $v\left(\frac{4}{3}\right)^{1/2}$ (b) $v\left(\frac{4}{3}\right)^{1/2}$
(c) $v\left(\frac{3}{4}\right)^{1/2}$ (d) greater than $v\left(\frac{4}{3}\right)^{1/2}$

25. Figure (a) shows a logic gate circuit with two inputs *A* and *B* and the output *C*.



(a)

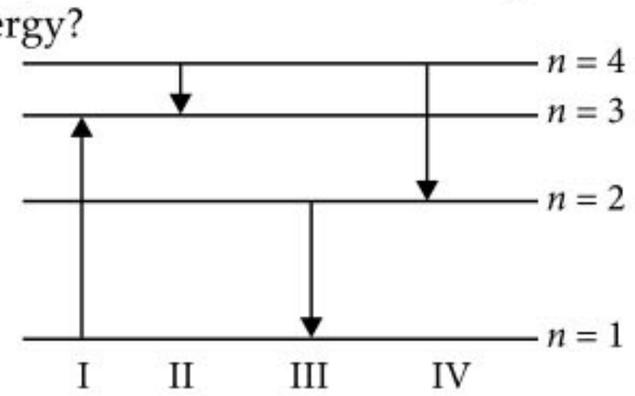
The voltage waveforms of *A*, *B* and *C* are as shown in figure (b).



(b)

The logic gate is
(a) OR gate (b) AND gate
(c) NAND gate (d) NOR gate

26. Figure shows the energy levels for an electron in a certain atom. Which of the following transitions shown, represents the emission of a photon with the most energy?



(a) III (b) IV (c) I (d) II

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27. A transistor is operated in common-emitter configuration at V_{CE} = 2 V such that a change in the base current from 100 μA to 200 μA produces a change in the collector current from 5 mA to 10 mA. The current gain is

(a) 100 (b) 150 (c) 50 (d) 75

28. If the kinetic energy of a free electron doubles, its de Broglie wavelength changes by the factor

(a) $1/\sqrt{2}$ (b) $\sqrt{2}$ (c) 1/2 (d) 2

29. A hydrogen atom emits a photon corresponding to an electron transition from $n = 5$ to $n = 1$. The recoil speed of hydrogen atom is almost (Take mass of proton = 1.6×10^{-27} kg)

(a) 10 m s^{-1} (b) 2×10^{-2} m s^{-1}
(c) 4 m s^{-1} (d) 8×10^{2} m s^{-1}

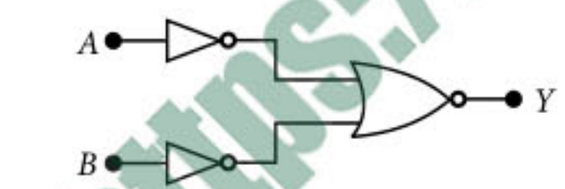
30. The maximum wavelength of a beam of light that can be used to produce photoelectric effect on a metal is 250 nm. The energy of the electrons (in joule) emitted from the surface of the metal when a beam of light of wavelength 200 nm is used, is

(a) 89.61×10^{-22} (b) 69.81×10^{-22}
(c) 18.96×10^{-20} (d) 19.86×10^{-20}

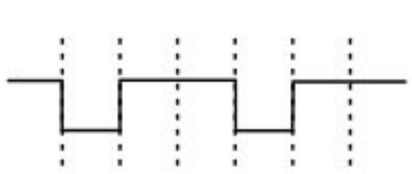
31. A radioactive nucleus of mass number A, initially at rest, emits an α-particle with a speed v. What will be the recoil speed of the daughter nucleus?

(a) $\frac{2v}{(A-4)}$ (b) $\frac{2v}{(A+4)}$ (c) $\frac{4v}{(A-4)}$ (d) $\frac{4v}{(A+4)}$

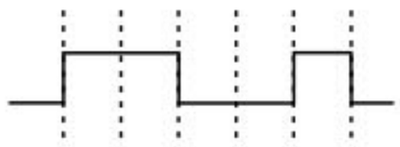
32. The logic circuit shown in figure has the input waveforms A and B as shown. Pick out the correct ouput waveform.



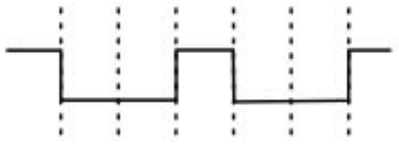
(a)



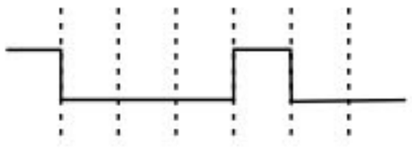
(b)



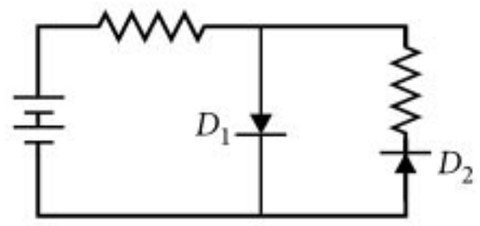
(c)



(d)



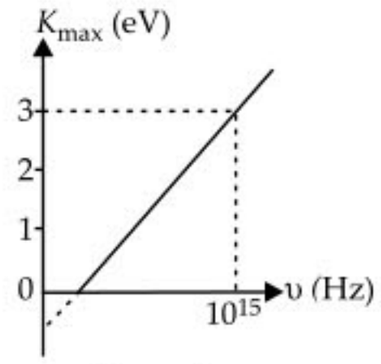
33. In the diode circuit shown in figure



(a) D_1 and D_2 are reverse biased
(b) D_1 and D_2 are forward biased
(c) D_1 is forward biased and D_2 is reverse biased
(d) D_1 is reverse biased and D_2 is forward biased

34. Figure represents a graph of kinetic energy of most energetic photoelectrons K_{max} (in eV) and frequency υ for a metal used as cathode in photoelectric experiment. The threshold frequency of light for the photoelectric emission from the metal is

(a) 1×10^{14} Hz
(b) 1.5×10^{14} Hz
(c) 2.1×10^{14} Hz
(d) 2.8×10^{14} Hz



35. The counting rate observed from a radioactive source at $t = 0$ was 1600 counts s^{-1}, and at $t = 8$ s, it was 100 counts s^{-1}. The counting rate observed as counts s^{-1} at $t = 6$ s will be

(a) 400 (b) 300 (c) 250 (d) 200

36. In a common emitter transistor, the base current $I_B = 2$ μA, $\alpha = 0.9$, then I_B is equal to

(a) 18 μ A (b) 20 μ A (c) 22 μ A (d) 24 μ A

37. An energy of 24.6 eV is required to remove one of the electrons from a neutral helium atom. The energy (in eV) required to remove both the electrons from a neutral helium atom is

(a) 38.2 (b) 49.2 (c) 51.8 (d) 79.0

38. The current gain of a transistor in common-emitter mode is 49. The change in collector current and emitter current corresponding to the change in base current by 5.0 μA will be

(a) 245 μA, 250 μA (b) 240 μA, 235 μA
(c) 260 μA, 255 μA (d) none of these

39. The input resistance of a silicon transistor is 665 Ω. Its base current is changed by 15 μA which results in the change in collector current by 2 mA. This transistor is used as a common emitter amplifier with a load resistance of 5 kΩ. What is the voltage gain of the amplifier?

(a) 1002.5 (b) 1232.8 (c) 7235.9 (d) 9879.3

40. Light of wavelength 5000 Å falls on a sensitive plate with photoelectric work function of 1.9 eV. The kinetic energy of the photoelectron emitted will be

(a) 0.58 eV (b) 2.48 eV
(c) 1.24 eV (d) 1.16 eV

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41. The wave number of the energy emitted when electrons comes from four orbit to second orbit in hydrogen is 20397 cm^{-1}. The wave number of the energy for the same transition in He^+ is

(a) 5,099 cm^{-1} (b) 20,497 cm^{-1}
(c) 14400 Å (d) 81,588 cm^{-1}

42. A photosensitive metallic surface has work function, $h\upsilon_0$. If photons of energy $2h\upsilon_0$ fall on this surface, the electrons come out with a maximum velocity of 4×10^6 ms^{-1}. When the photon energy is increased to $5h\upsilon_0$, then maximum velocity of photoelectrons will be

(a) 2×10^7 m s^{-1} (b) 2×10^6 m s^{-1}
(c) 8×10^6 m s^{-1} (d) 8×10^5 m s^{-1}

43. An energy of 24.6 eV is required to remove one of the electrons from a neutral helium atom. The energy (in eV) required to remove both the electrons from a neutral helium atom is

(a) 38.2 (b) 49.2
(c) 51.8 (d) 79.0

44. A TV tower is 120 m high. How much more height is to be added to it, if its coverage range is to become double?

(a) 120 m (b) 240 m
(c) 360 m (d) 480 m

45. A message signal of frequency 10 kHz and peak value of 10 volts is used to moderate a carrier of frequency 1 MHz and peak voltage 20 volts. The modulation index and side bands produced are

(a) 0.4 and 1200 kHz, 990 kHz
(b) 0.5 and 1010 kHz, 990 kHz
(c) 0.2 and 1010 kHz, 1000 kHz
(d) 0.5 and 1500 kHz, 1000 Hz

UNIT TEST 5 OMR SHEET

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____

(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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MOCK TEST PAPER 1

Max. Marks : 180 **Time : 45 min.**

1. A 15 g ball is shot from a spring gun whose spring has a force constant 600 N m^{-1}. The spring is compressed by 5 cm. The greatest possible horizontal range of the ball for this compression (Take $g = 10\ m\ s^{-2}$)
(a) 6 m (b) 8 m (c) 10 m (d) 12 m

2. Two weights w_1 and w_2 are suspended from the ends of a light string over a smooth fixed pulley. If the pulley is pulled up with acceleration g, the tension in the string will be
(a) $\frac{4w_1w_2}{w_1+w_2}$ (b) $\frac{2w_1w_2}{w_1+w_2}$
(c) $\frac{w_1-w_2}{w_1+w_2}$ (d) $\frac{w_1w_2}{2(w_1+w_2)}$

3. A gas bubble from an explosion under water oscillates with a time period T, depends upon static pressure p, density of water ρ and the total energy of explosion E. Find the expression for the time period T. k is a dimensionless constant.
(a) $T = kp^{-5/6}\rho^{1/2}E^{1/3}$ (b) $T = kp^{-4/7}\rho^{1/2}E^{1/3}$
(c) $T = kp^{-5/6}\rho^{1/2}E^{1/2}$ (d) $T = kp^{-4/7}\rho^{1/3}E^{1/2}$

4. A charged particle of mass m and charge q is released from rest in an electric field of constant magnitude E. The kinetic energy of the particle after time t is
(a) $\frac{E^2q^2t^2}{2m}$ (b) $\frac{2E^2t^2}{qm}$
(c) $\frac{Eqm}{2t}$ (d) $\frac{Eq^2m}{2t^2}$

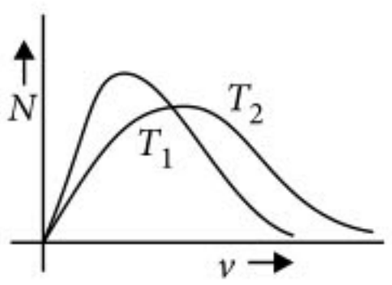
5. The intensity of magnetic field at a point X on the axis of a small magnet is equal to the field intensity at another point Y on its equatorial axis. The ratio of distances of X and Y from the centre of the magnet will be
(a) $(2)^{-3}$ (b) $(2)^{-1/3}$ (c) 2^3 (d) $2^{1/3}$

6. 5 mole of an ideal gas with $\gamma = 7/5$ initially at STP are compressed adiabatically so that its temperature becomes 400°C. The increase in the internal energy of gas in kJ is
(a) 21.55 (b) 41.55 (c) 65.55 (d) 50.55

7. A circular platform is mounted on a frictionless vertical axle. Its radius $R = 2$ m and its moment of inertia about the axle is 200 kg m^2. It is initially at rest. A 50 kg man stands on the edge of the platform and begins to walk along the edge at the speed of 1 m s^{-1} relative to the ground. Time taken by the man to complete one revolution with respect to disc is
(a) π s (b) $\frac{3\pi}{2}$ s (c) 2π s (d) $\frac{\pi}{2}$ s

8. A vessel contains oil (density = 0.8 g cm^{-3} over mercury (density = 13.6 g cm^{-3}). A uniform sphere floats with half its volume immersed in mercury and the other half in oil. The density of the material of sphere in g cm^{-3} is
(a) 3.3 (b) 6.4 (c) 7.2 (d) 12.8

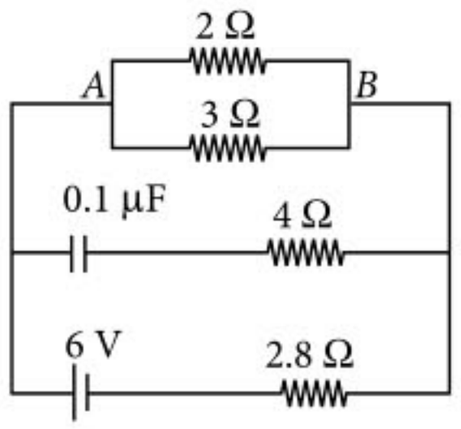
9. Maxwell's velocity distribution curve is given for the same quantity at two different temperatures. For the given curves



(a) $T_1 > T_2$
(b) $T_1 < T_2$
(c) $T_1 \le T_2$ (d) $T_1 = T_2$

10. Two capacitors of 25 μF and 100 μF are connected in series to a source of 120 V. Keeping their charges unchanged, they are separated and connected in parallel to each other. Find out energy loss in the process.
(a) 5.2 J (b) 52 J (c) 50.2 J (d) 0.052 J

11. The steady state current in a 2 Ω resistor when the internal resistance of the battery is negligible and the capacitance of the condenser is 0.1 μF is
(a) 0.6 A
(b) 0.9 A
(c) 1.5 A
(d) 0.3 A



12. In an experiment, a magnet with its magnetic moment along the axis of a circular coil and directed towards the coil, is withdrawn away from the coil and parallel to itself. The current in the coil, as seen by the withdrawing magnet, is

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(a) zero (b) clockwise
(c) anticlockwise (d) first (a) then (b)

13. A luminous object is placed at a distance of 30 cm from the convex lens of focal length 20 cm. On the other side of the lens, at what distance from the lens a convex mirror of radius of curvature 10 cm be placed in order to have an inverted image of the object coincident with it?
(a) 12 cm (b) 30 cm (c) 50 cm (d) 60 cm

14. Two slits separated by a distance of 1 mm are illuminated with red light of wavelength 6.5×10^{-7} metre. The interference fringes are observed on a screen placed one metre from the slits. The distance between the third dark fringe and fifth bright fringe on the same side of centre is equal to
(a) 0.65 mm (b) 1.63 mm
(c) 3.25 mm (d) 4.8 mm

15. An electric bulb is marked 100 W, 230 V. If the supply voltage drops to 115 V, what is the heat and light energy produced by the bulb in 20 min?
(a) 10 kJ (b) 15 kJ (c) 20 kJ (d) 30 kJ

16. A body hanging from a spring stretches it by 1 cm at the earth's surface. How much will the same body stretch the spring at a place 16400 km above the earth's surface? (Radius of the earth = 6400 km)
(a) 1.28 cm (b) 0.64 cm (c) 3.6 cm (d) 0.12 cm

17. A resistor R and 2 μF capacitor in series are connected through a 200 V direct supply. Across the capacitor is a neon bulb that lights up at 120 V. Find the value of R to make the bulb light up 5 s after the switch has been closed. (Take $\log_{10} 2.5 = 0.4$)
(a) $1.7 \times 10^5\ \Omega$ (b) $2.7 \times 10^6\ \Omega$
(c) $3.3 \times 10^7\ \Omega$ (d) $1.3 \times 10^4\ \Omega$

18. A coil of resistance 400 Ω is placed in a magnetic field. If the magnetic flux ϕ (Wb) linked with the coil varies with time t (s) as $\phi = 50t^2 + 4$. The current in the coil at $t = 2$ s is
(a) 0.5 A (b) 0.1 A (c) 2 A (d) 1 A

19. An electromagnetic wave of frequency 3 MHz passes from vacuum into a dielectric medium with permittivity $\varepsilon_r = 4$, then
(a) the wavelength and frequency both remain unchanged
(b) the wavelength is doubled and the frequency remains unchanged
(c) the wavelength is doubled and the frequency becomes half
(d) the wavelength is halved and the frequency remains unchanged.

20. A polyster fibre rope of diameter 3 cm has a breaking strength of 150 kN. If it is required to have 600 kN breaking strength. What should be the diameter of similar rope?
(a) 12 cm (b) 6 cm (c) 3 cm (d) 1.5 cm

21. A thin uniform rod of mass m moves translationally with acceleration a due to two antiparallel forces of lever arm l. One force is of magnitude F and acts at one extreme end. The length of the rod is
(a) $\dfrac{mal}{ma+F}$ (b) $\dfrac{2(F+ma)l}{ma}$
(c) $l\left(l+\dfrac{F}{ma}\right)$ (d) $\dfrac{(F+ma)l}{2ma}$

22. The amount of work done in stretching a spring from a stretched length of 10 cm to a stretched length of 20 cm is
(a) equal to the work done in stretching it from 20 cm to 30 cm
(b) less than the work done in stretching it from 20 cm to 30 cm
(c) more than the work done in stretching it from 20 cm to 30 cm
(d) equal to the work done in stretching it from 0 to 10 cm.

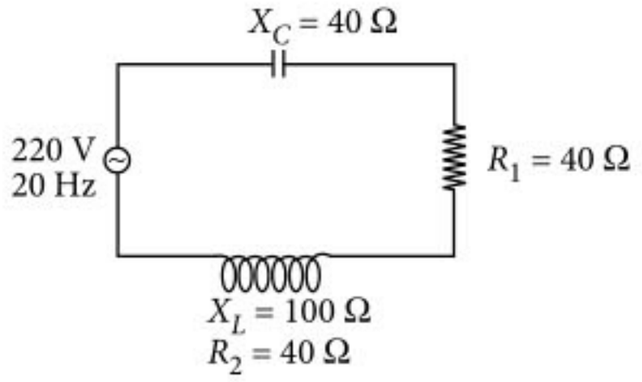
23. The rms value of the electric field of the light coming from the sun is 720 N C^{-1}. The average total energy density of the electromagnetic wave is
(a) 3.3×10^{-3} J m^{-3} (b) 4.58×10^{-6} J m^{-3}
(c) 6.37×10^{-9} J m^{-3} (d) 81.35×10^{-12} J m^{-3}

24. In Young's double slit experiment, one of the slits is wider than the other, so that the amplitude of the light from one slit is double that from the other slit. If I_m be the maximum intensity, the resultant intensity when they interfere at phase difference ϕ is given by
(a) $\dfrac{I_m}{3}\left(1+2\cos^2\dfrac{\phi}{2}\right)$ (b) $\dfrac{I_m}{5}\left(1+4\cos^2\dfrac{\phi}{2}\right)$
(c) $\dfrac{I_m}{9}\left(1+8\cos^2\dfrac{\phi}{2}\right)$ (d) $\dfrac{I_m}{9}\left(8+\cos^2\dfrac{\phi}{2}\right)$

25. A compound microscope has an eye piece of focal length 10 cm and an objective of focal length 4 cm. Calculate the magnification, if an object is kept at a distance of 5 cm from the objective, so that the final image is formed at the least distance of distinct vision 20 cm.
(a) 12 (b) 11 (c) 10 (d) 13

26. In a galvanometer 5% of the total current in the circuit passes through it. If the resistance of the galvanometer is G, the shunt resistance S connected to the galvanometer is
(a) $19G$ (b) $\dfrac{G}{19}$ (c) $20G$ (d) $\dfrac{G}{20}$

27. The power factor of the circuit as shown in figure is



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(a) 0.2 (b) 0.4
(c) 0.8 (d) 0.6

28. At ordinary temperature, the molecules of an ideal gas have only translational and rotational kinetic energies. At high temperatures they may also have vibrational energy. As a result of this at higher temperatures (C_V = molar heat capacity at constant volume)

(a) $C_V = \frac{3}{2}R$ for a monoatomic gas

(b) $C_V > \frac{3}{2}R$ for a monoatomic gas

(c) $C_V > \frac{5}{2}R$ for a diatomic gas

(d) $C_V = \frac{5}{2}R$ for a diatomic gas

29. A body is projected vertically upwards with a velocity of 10 m s^{-1}. It reaches the maximum height h in time t. In time $t/2$, the height covered is

(a) $\frac{h}{2}$ (b) $\frac{2}{5}h$ (c) $\frac{3}{4}h$ (d) $\frac{5}{8}h$

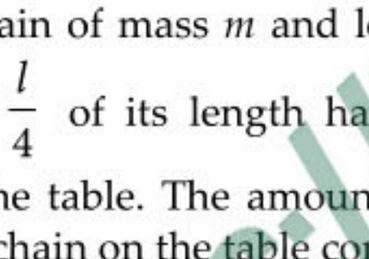
30. A wheel is subjected to uniform angular acceleration about its axis. Initially, its angular velocity is zero. In the first 2 s, it rotates through an angle θ_1, in the next 2 s, it rotates through an angle θ_2. The ratio of $\frac{\theta_2}{\theta_1}$ is

(a) 1 (b) 2 (c) 3 (d) 5

31. A uniform chain of mass m and length l is lying on a table with $\frac{l}{4}$ of its length hanging freely from the edge of the table. The amount of work done in dragging the chain on the table completely is

(a) $\frac{mgl}{4}$ (b) $\frac{mgl}{8}$ (c) $\frac{mgl}{32}$ (d) $\frac{mgl}{16}$

32. The diode used in the circuit shown in the figure has a constant voltage drop at 0.5 V at all currents and a maximum power rating of 100 milliwatts. What should be the value of the resistor R, connected in series with diode, for obtaining maximum current?



(a) 6.76 Ω (b) 20 Ω (c) 5 Ω (d) 5.6 Ω

33. The half-life of a radioactive isotope X is 50 years. It decays to another element Y which is stable. The two elements X and Y were found to be in the ratio of 1 : 15 in a sample of a given rock. The age of the rock was estimated to be

(a) 100 years (b) 150 years
(c) 200 years (d) 250 years

34. On shining light of wavelength 6.2×10^{-6} m on a metal surface photo-electrons are emitted. The work function of the metal is 0.1 eV. Find the kinetic energy of a photo-electron (in eV)

(a) 0.1 (b) 0.2 (c) 0.3 (d) 0.4

35. A mass of 0.2 kg is attached to the lower end of a massless spring of force constant 200 N m^{-1}, the upper end of which is fixed to a rigid support. Which of the following statement is not true?

(a) The frequency of oscillation will be nearly 5 Hz.
(b) In equilibrium, the spring will be stretched by 2 cm.
(c) If the mass is raised till the spring is unstretched state and then released, it will go down by 2 cm before moving upward
(d) If the system is taken to a planet, the frequency of oscillation will be the same as on the earth.

36. The equation of a wave is represented by $Y = 10^{-5}\sin\left[100t - \frac{x}{10}\right]$ m, then the velocity of wave will be

(a) 100 m s^{-1} (b) 4 m s^{-1}
(c) 1000 m s^{-1} (d) zero

37. Force on a 1 kg mass on earth of radius R is 10 N. Then the force on a satellite revolving around the earth in the mean orbital radius $3R/2$ will be (mass of satellite is 100 kg)

(a) 4.44×10^2 N (b) 3.33×10^2 N
(c) 500 N (d) 6.66×10^2 N

38. The far point of a near sighted person is 6.0 m from her eyes, and she wears contacts that enable her to see distant objects clearly. A tree is 18.0 m away and 2.0 m high. How high is the image formed by the contacts?

(a) 1.0 m (b) 1.5 m
(c) 0.75 m (d) 0.50 m

39. You drive a car at a speed of 70 km h^{-1} in a straight road for 8.4 km and then the car runs out of petrol. You walk for 30 min to reach a petrol pump at a distance of 2 km. The average velocity from the beginning of your drive till you reach the petrol pump is

(a) 16.8 km h^{-1} (b) 35 km h^{-1}
(c) 64 km h^{-1} (d) 18.6 km h^{-1}

40. A fork A has frequency 2% more than the standard fork and B has a frequency 3% less than the frequency of same standard fork. The forks A and B when sounded together produced 6 beats s^{-1}. The frequency of fork A is

(a) 116.4 Hz (b) 120 Hz
(c) 122.4 Hz (d) 238.8 Hz

41. When a wire of length 10 m is subjected to a force of 100 N along its length, the lateral strain produced is 0.01×10^{-3}. The Poisson's ratio was found to be 0.4. If the area of cross-section of wire is 0.025 m^2, its Young's modulus is

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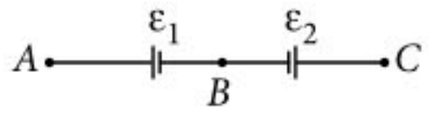
(a) 1.6×10^8 N m^{-2} (b) 2.5×10^{10} N m^{-2}
(c) 1.25×10^{11} N m^{-2} (d) 16×10^9 N m^{-2}

42. In an experiment on photoelectric emission from a metallic surface, wavelength of incident light is 2×10^{-7} m and stopping potential is 2.5 V. The threshold frequency of the metal is approximately (Charge of electron $e = 1.6 \times 10^{-19}$ C, Planck's constant $h = 6.6 \times 10^{-34}$ J s)

(a) 12×10^{15} Hz (b) 9×10^{15} Hz
(c) 9×10^{14} Hz (d) 12×10^{13} Hz

43. Two cells of emf ε_1 and ε_2 ($\varepsilon_1 > \varepsilon_2$) are connected as shown in figure. When a potentiometer is connected between A and B, the balancing length of the potentiometer wire is 300 cm. On connecting the same potentiometer between A and C, the balancing length is 100 cm. The ratio is $\varepsilon_1 : \varepsilon_2$ is



(a) 3 : 1 (b) 1 : 3
(c) 2 : 3 (d) 3 : 2

44. A body is thrown horizontally from the top of a tower of 5 m height. It touches the ground at a distance of 10 m from the foot of the tower. The initial velocity of the body is (Take g = 10 m s^{-2})

(a) 2.5 m s^{-1} (b) 5 m s^{-1}
(c) 10 m s^{-1} (d) 20 m s^{-1}

45. Two bodies of 6 kg and 4 kg masses have their velocity $5\hat{i}-2\hat{j}+10\hat{k}$ and $10\hat{i}-2\hat{j}+5\hat{k}$ respectively. Then the velocity of their centre of mass is

(a) $5\hat{i}+2\hat{j}-8\hat{k}$ (b) $7\hat{i}+2\hat{j}-8\hat{k}$
(c) $7\hat{i}-2\hat{j}+8\hat{k}$ (d) $5\hat{i}-2\hat{j}+8\hat{k}$

DAY 30 OMR SHEET 1

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ
Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
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(1) Number of questions attempted : _____ (3) Marks scored : _____
(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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MOCK TEST PAPER 2

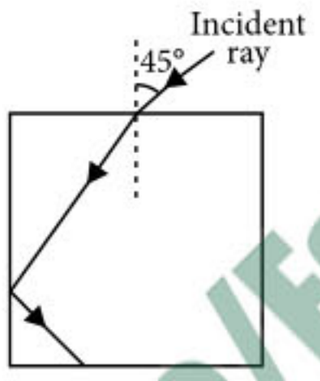
Max. Marks : 180 **Time : 45 min.**

1. If the momentum of electron is changed by p, then the de Broglie wavelength associated with it changes by 0.5%. The initial momentum of electron will be
(a) $200\,p$ (b) $400\,p$ (c) $(p/200)$ (d) $100\,p$

2. To what temperature must a hydrogen sample be heated so that the average molecular energy equals the binding energy of the hydrogen atom?
(Take $k = 1.38 \times 10^{-22}$ J K^{-1})
(a) 1×10^4 K (b) 1×10^5 K
(c) 2×10^6 K (d) 7×10^3 K

3. You measure two quantities as $A = 1.0$ m $\pm$ 0.2m, $B = 2$ m $\pm$ 0.2 m. We should report correct value for $\sqrt{AB}$ as
(a) 1.4 m $\pm$ 0.4 m (b) 1.41 m $\pm$ 0.15 m
(c) 1.4 m $\pm$ 0.3 m (d) 1.4 m $\pm$ 0.2 m

4. For the given incident ray as shown in figure, the condition of total internal reflection of ray will be satisfied if the refractive index of block will be

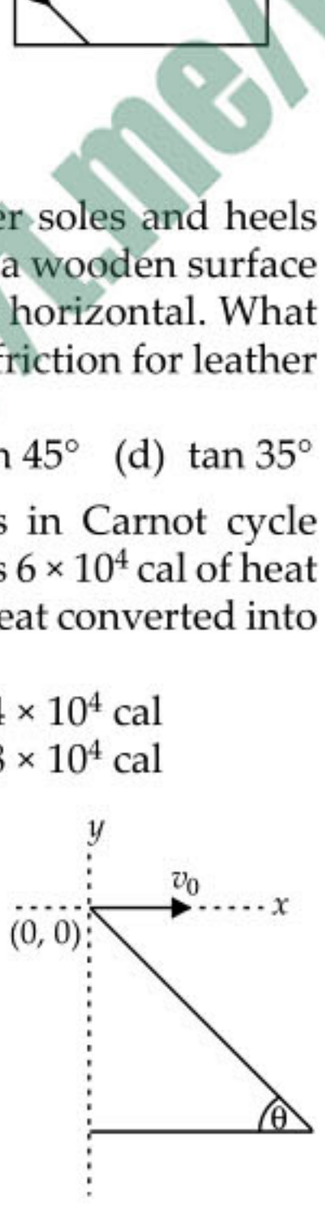


(a) $\frac{\sqrt{3}+1}{2}$ (b) $\frac{\sqrt{2}+1}{2}$
(c) $\sqrt{\frac{3}{2}}$ (d) $\sqrt{\frac{7}{6}}$

5. A woman whose shoes have leather soles and heels is able to stand without slipping on a wooden surface that makes an angle of 25° with the horizontal. What is the minimum coefficient of static friction for leather on wood?
(a) tan 25° (b) tan 75° (c) tan 45° (d) tan 35°

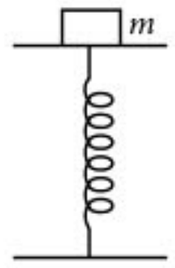
6. An ideal gas heat engine operates in Carnot cycle between 227°C and 127°C. It absorbs 6×10^4 cal of heat of higher temperature. Amount of heat converted into work is
(a) 1.2×10^4 cal (b) 2.4×10^4 cal
(c) 6×10^4 cal (d) 4.8×10^4 cal

7. A man standing on a hill top projects a stone horizontally with speed v_0 as shown in figure. Taking the coordinate system as given in the figure. The coordinates of the point where the stone will hit the hill surface



(a) $\left(\frac{2v_0^2\tan\theta}{g}, \frac{-2v_0^2\tan^2\theta}{g}\right)$
(b) $\left(\frac{2v_0^2}{g}, \frac{2v_0^2\tan^2\theta}{g}\right)$ (c) $\left(\frac{2v_0^2\tan\theta}{g}, \frac{2v_0^2}{g}\right)$
(d) $\left(\frac{2v_0^2\tan^2\theta}{g}, \frac{2v_0^2\tan^2\theta}{g}\right)$

8. A mass of 2.0 kg is put on a flat pan attached to a vertical spring fixed on the ground as shown in figure. The mass of the spring and the pan is negligible. When pressed slightly and released the mass executes simple harmonic motion.
The spring constant is 200 N m^{-1}. What should be the minimum amplitude of motion so that the mass gets detached from the pan. (Take $g = 10$ m s^{-2})



(a) 10.0 cm
(b) 8.0 cm
(c) 6.0 cm
(d) any value less than 10.0 cm

9. Charge Q is divided into two parts which are then kept some distance apart. The force between them will be maximum if the two parts are
(a) $Q/2$ each
(b) $Q/4$ and $3Q/4$
(c) $Q/3$ and $2Q/3$
(d) e and $(Q - e)$, where e = electronic charge

10. A plate of thickness t made of a material of refractive index μ is placed in front of one of the slits in a double slit experiment. What should be the minimum thickness t, which will make the intensity at the centre of the fringe pattern zero?
(a) $(\mu-1)\frac{\lambda}{2}$ (b) $\frac{\lambda}{(\mu-1)}$ (c) $\frac{\lambda}{2(\mu-1)}$ (d) $(\mu-1)\lambda$

11. A boat covers a given distance in 6 h moving down stream of a river. It covers the same distance in 10 h moving upstream. The time (in hour) it takes to cover the same distance in still water is
(a) 6 h (b) 7.5 h (c) 10 h (d) 15 h

12. A gas is at pressure 6×10^5 N m^{-2} and volume 1 m^3 and its pressure falls to 4×10^5 N m^{-2} when its volume is 3 m^3. Given that the indicator diagram is a straight line, work done by the system is
(a) 6×10^5 J (b) 3×10^5 J
(c) 4×10^5 J (d) 10×10^5 J

13. A non conducting ring of radius R has charge Q distributed unevenly over it. If it rotates with an angular velocity ω, the equivalent current will be
(a) zero (b) $Q\omega$
(c) $Q\frac{\omega}{2\pi}$ (d) $Q\frac{\omega}{2\pi R}$

14. An irregular closed loop carrying a current has a shape such that the entire loop cannot lie in a single plane. If this is placed in a uniform magnetic field, the force acting on the loop
(a) must be zero
(b) can never be zero
(c) may be zero
(d) will be zero only for one particular direction of the magnetic field

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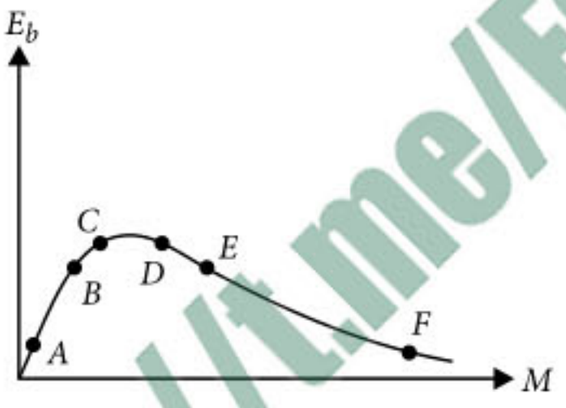
15. Two sources of sound placed close to each other are emitting progressive waves given by
$y_1 = 4\sin 600\pi t$ and $y_2 = 5\sin 608\pi t$
An observer located near these two sources of sound will hear
(a) 4 beats per second with intensity ratio 25 : 16 between waxing and waning
(b) 8 beats per second with intensity ratio 25 : 16 between waxing and waning
(c) 8 beats per second with intensity ratio 81 : 1 between waxing and waning
(d) 4 beats per second with intensity ratio 81 : 1 between waxing and waning.

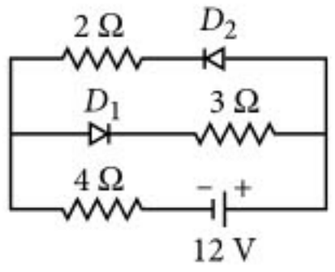
16. In a parallel-plate capacitor, the region between the plates is filled by a dielectric slab. The capacitor is charged from a cell and then disconnected from it. The slab is now taken out.
(a) The potential difference across the capacitor is reduced.
(b) The potential difference across the capacitor is increased.
(c) The energy stored in the capacitor is reduced.
(d) No work is done by an external agent in taking the slab out.

17. Given figure is a plot of binding energy per nucleon E_b against the nuclear mass M. A, B, C, D, E and F correspond to different nuclei. Consider four reactions



(i) $A + B \rightarrow C + Q$
(ii) $C \rightarrow A + B + Q$
(iii) $D + E \rightarrow F + Q$
(iv) $F \rightarrow D + E + Q$
where Q is the energy released.
In which reactions is Q positive?
(a) (i) and (iv) (b) (i) and (iii)
(c) (ii) and (iv) (d) (ii) and (iii)

18. The circuit has two oppositely conncected ideal diodes in parallel. What is the current flowing in the circuit?



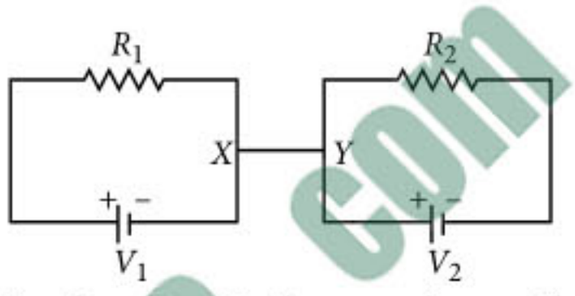
(a) 1.71 A (b) 2.0 A
(c) 231 A (d) 1.33 A

19. 100 g of an iron ball having velocity 10 m s^{-1} collides with wall at an angle 30° and rebounds with the same angle. If the period of contact between the ball and wall is 0.1 s, then the average force experienced by the wall is
(a) 10 N (b) 100 N (c) 1.0 N (d) 0.1 N

20. A body of mass M slides down an inclined and reaches the bottom with a velocity v if the same mass were in the form of a ring which rolls down the incline, the velocity of the ring at bottom
(a) v (b) $\sqrt{2}v$ (c) $\frac{1}{\sqrt{2}}v$ (d) $\sqrt{\frac{2}{5}}v$

21. Equation of a plane progressive wave is given by $y = 0.6\sin 2\pi\left(t - \frac{x}{2}\right)$. On reflection from a denser medium, its amplitude becomes 2/3 of the amplitude of the incident wave. The equation of the reflected wave is
(a) $y = 0.6\sin 2\pi\left(t + \frac{x}{2}\right)$
(b) $y = -0.4\sin 2\pi\left(t + \frac{x}{2}\right)$
(c) $y = 0.4\sin 2\pi\left(t + \frac{x}{2}\right)$
(d) $y = -0.4\sin 2\pi\left(t - \frac{x}{2}\right)$

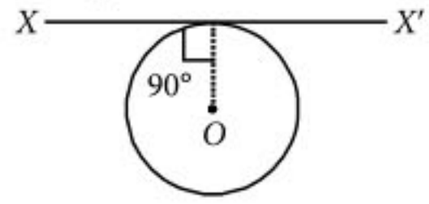
22.



In the circuit shown above, the conductor XY is of negligible resistance. Then
(a) current will flow through XY if $V_1 \neq V_2$
(b) current will flow through XY if $\frac{V_1}{R_1} \neq \frac{V_2}{R_2}$
(c) current will flow through XY if $\frac{V_1 + V_2}{R_1 + R_2} \neq \frac{|V_1 - V_2|}{R_1 - R_2}$
(d) no current will flow through XY

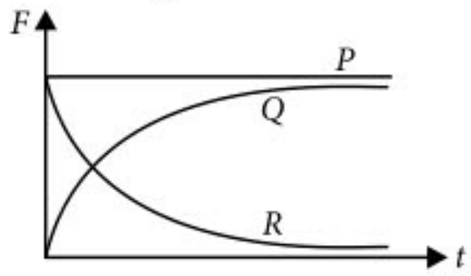
23. A transformer is used to light a 100 W, 110 V lamp from 220 V mains. If main current is 0.5 A, efficiency of transformer is
(a) 90% (b) 95% (c) 96% (d) 99%

24. A thin wire of length L and uniform linear mass density ρ is bent into a circular loop with centre at O as shown.
The moment of inertia of the loop about the axis XX' is



(a) $\frac{\rho L^3}{8\pi^2}$ (b) $\frac{\rho L^3}{16\pi^2}$ (c) $\frac{5\rho L^3}{16\pi^2}$ (d) $\frac{3\rho L^3}{8\pi^2}$

25. A spherical ball is dropped in a long column of viscous liquid. Which of the following graphs represent the variation of
(i) gravitational force with time
(ii) viscous force with time
(iii) net force acting on the ball with time?



(a) Q, R, P (b) R, Q, P (c) P, Q, R (d) R, P, Q

26. A milliammeter of range 10 mA has coil of resistance 1 Ω. To use it as an ammeter of range 1 A, the required shunt must have a resistance of

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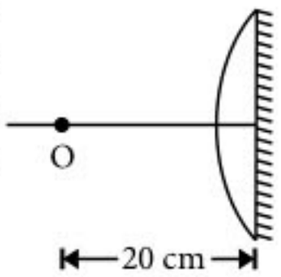
(a) $\frac{1}{101}\Omega$ (b) $\frac{1}{100}\Omega$ (c) $\frac{1}{99}\Omega$ (d) $\frac{1}{9}\Omega$

27. A point object is placed at a distance of 20 cm from a thin planoconvex lens of focal length 15 cm. The plane surface of the lens is now silvered. The image formed by the system is at



(a) 60 cm to the left of the system
(b) 60 cm to the right of the system
(c) 12 cm to the left of the system
(d) 12 cm to the right of the system

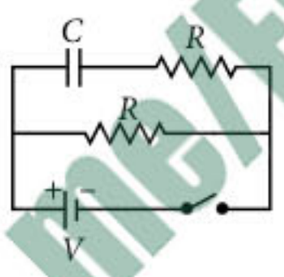
28. Light of two different frequencies whose photons have energies 1 eV and 2.5 eV respectively, successively illuminate a metallic surface whose work function is 0.5 eV. Ratio of maximum speeds of emitted electrons will be

(a) 1 : 5 (b) 1 : 4 (c) 1 : 2 (d) 1 : 1

29. Two small balls of same size and masses m_1 and $m_2 (m_1 > m_2)$ are tied by a thin massless thread and dropped from a certain height. Upward buoyant force F comes into account, the tension T of the thread during the flight after the motion of the ball becomes uniform will be

(a) $(m_1 - m_2)g$ (b) $(m_1 - m_2)g/2$
(c) $(m_1 + m_2)g$ (d) $(m_1 + m_2)g/2$

30. In the circuit shown, when the switch is closed, the capacitor charges with a time constant



(a) RC (b) $2RC$
(c) $\frac{1}{2}RC$ (d) $RC \ln 2$

31. One requires 11 eV of energy to dissociate a carbon monoxide molecule into carbon and oxygen atoms. The minimum frequency of the appropriate electromagnetic radiation to achieve the dissociation lies in

(a) visible region (b) infrared region
(c) ultraviolet region (d) microwave region

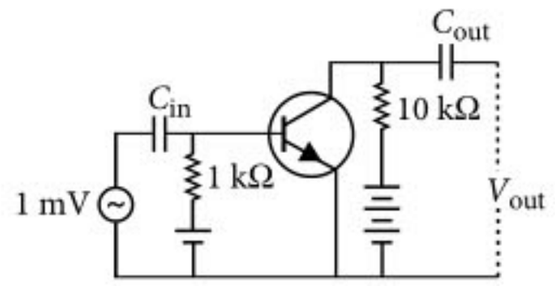
32. When an unpolarised light of intensity I_0 is incident on a polarising sheet, the intensity of the light which does not get transmitted is

(a) $\frac{I_0}{2}$ (b) $\frac{I_0}{4}$ (c) zero (d) I_0

33. The Bohr model cannot be directly applied to calculate the energy levels of an atom with many electrons. This is because

(a) of the electrons not being subject to a central force
(b) of the electrons colliding with each other
(c) of screening effects
(d) the force between the nucleus and an electron will no longer be given by Coulomb's law.

34. In the common-emitter configuration, an n-p-n transistor with current gain = 100 is used. The output voltage of the amplifier will be

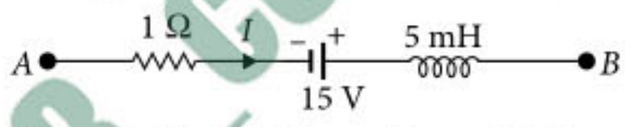


(a) 10 mV (b) 0.1 V (c) 1.0 V (d) 10 V

35. A 30 kg crate is pulled up a ramp 15 m long and 2 m high by a constant force of 100 N. The crate starts from rest and has a velocity of 2 m s^{-1} when it reaches the top of the ramp. What is the frictional force between the crate and the ramp?

(a) 28 N (b) 57 N (c) 15 N (d) 90 N

36. The network shown in the figure is part of a complete circuit. If at a certain instant, the current I is 5 A, and is decreasing at a rate 10^3 A s^{-1} then $V_B - V_A$ is



(a) 20 V (b) 15 V (c) 10 V (d) 5 V

37. A plane electromagnetic wave of frequency 25 MHz travels in a free space along the x-direction. At the particular point in space and time, $E = 6.3\hat{j}$ V m^{-1}. What is the magnetic field at that point?

(a) $2.1\times10^{-8}\hat{k}$ T (b) $3.1\times10^{-4}\hat{k}$ T
(c) $5.0\times10^{-6}\hat{k}$ T (d) 0

38. Both Earth and Moon are subject to the gravitational force of the Sun. As observed from the Sun, the orbit of the Moon

(a) will be elliptical
(b) will not be strictly elliptical because the total gravitational force on its is not central
(c) is not elliptical but will necessarily be a closed curve
(d) deviates considerably from being elliptical due to influence of planets other than Earth.

39. A circular loop of radius R, carrying current I, lies in x-y plane with its centre at origin. The total magnetic flux through x-y plane is

(a) directly proportional to I
(b) directly proportional to 5
(c) inversely proportional to R
(d) zero.

40. n-alpha particles per second are emitted from N atoms of a radioactive element. The half-life of the radioactive element is

(a) $\frac{n}{N}$ s (b) $\frac{N}{n}$ s
(c) $\frac{0.693N}{n}$ s (d) $\frac{0.693n}{N}$ s

41. For a heavily doped n-type semiconductor, Fermi level lies

(a) a little below the conduction band
(b) a little above the valence band
(c) a little inside the valence band
(d) at the centre of the band gap

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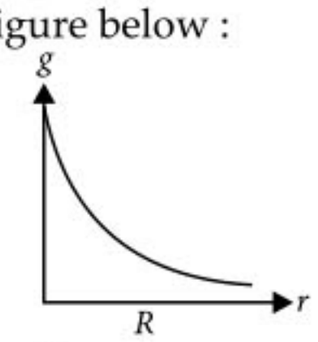
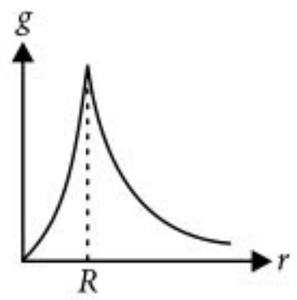
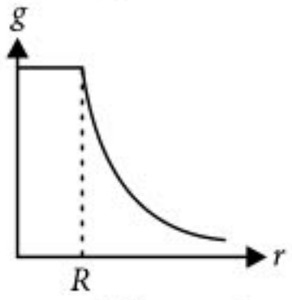
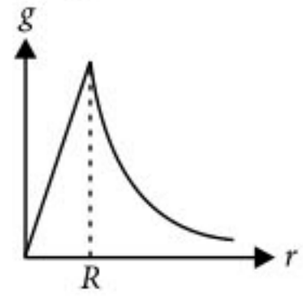
42. The dependence of acceleration due to gravity g on the distance r from the centre of the earth, assumed to be a sphere of radius R of uniform density is as shown in figure below :

1. 

2. 

3. 

4. 

The correct figure is

(a) 4 (b) 1 (c) 2 (d) 3

43. Two containers of equal volume contain the same gas at pressures P_1 and P_2 and absolute temperatures T_1 and T_2 respectively. On joining the vessels, the gas reaches a common pressure P and a common temperature T. The ratio P/T is equal to

(a) $\frac{P_1}{T_1}+\frac{P_2}{T_2}$ (b) $\frac{1}{2}\left[\frac{P_1}{T_1}+\frac{P_2}{T_2}\right]$

(c) $\frac{P_1T_2+P_2T_1}{T_1+T_2}$ (d) $\frac{P_1T_2-P_2T_1}{T_1-T_2}$

44. The molar heat capacity of a gas at constant volume is C_V. If n moles of the gas undergo ΔT change in temperature, its internal energy will change by $nC_V\Delta T$

(a) only if the change of temperature occurs at constant volume

(b) only if the change of temperature occurs at constant pressure

(c) in any process which is not adiabatic

(d) in any process.

45. An iceberg is floating partly immersed in sea water, the density of sea water is 1.03 g cm^{-3} and that of ice is 0.92 g cm^{-3}. The fraction of the total value of the iceberg above the level of sea water is

(a) 8.1% (b) 11% (c) 34% (d) 0.8%

DAY 30 OMR SHEET 2

Time : 45 min

INSTRUCTIONS

- Use HB pencil only and darken each circle completely.
- If you wish to change your answer, erase the already darkened circle completely and then darken the appropriate circle.
- Mark only one choice for each question as indicated.

Correct marking ● ⓑ ⓒ ⓓ

Wrong marking ⊗ ✓ ◑ ⊙

1. ⓐ ⓑ ⓒ ⓓ	10. ⓐ ⓑ ⓒ ⓓ	19. ⓐ ⓑ ⓒ ⓓ	28. ⓐ ⓑ ⓒ ⓓ	37. ⓐ ⓑ ⓒ ⓓ
2. ⓐ ⓑ ⓒ ⓓ	11. ⓐ ⓑ ⓒ ⓓ	20. ⓐ ⓑ ⓒ ⓓ	29. ⓐ ⓑ ⓒ ⓓ	38. ⓐ ⓑ ⓒ ⓓ
3. ⓐ ⓑ ⓒ ⓓ	12. ⓐ ⓑ ⓒ ⓓ	21. ⓐ ⓑ ⓒ ⓓ	30. ⓐ ⓑ ⓒ ⓓ	39. ⓐ ⓑ ⓒ ⓓ
4. ⓐ ⓑ ⓒ ⓓ	13. ⓐ ⓑ ⓒ ⓓ	22. ⓐ ⓑ ⓒ ⓓ	31. ⓐ ⓑ ⓒ ⓓ	40. ⓐ ⓑ ⓒ ⓓ
5. ⓐ ⓑ ⓒ ⓓ	14. ⓐ ⓑ ⓒ ⓓ	23. ⓐ ⓑ ⓒ ⓓ	32. ⓐ ⓑ ⓒ ⓓ	41. ⓐ ⓑ ⓒ ⓓ
6. ⓐ ⓑ ⓒ ⓓ	15. ⓐ ⓑ ⓒ ⓓ	24. ⓐ ⓑ ⓒ ⓓ	33. ⓐ ⓑ ⓒ ⓓ	42. ⓐ ⓑ ⓒ ⓓ
7. ⓐ ⓑ ⓒ ⓓ	16. ⓐ ⓑ ⓒ ⓓ	25. ⓐ ⓑ ⓒ ⓓ	34. ⓐ ⓑ ⓒ ⓓ	43. ⓐ ⓑ ⓒ ⓓ
8. ⓐ ⓑ ⓒ ⓓ	17. ⓐ ⓑ ⓒ ⓓ	26. ⓐ ⓑ ⓒ ⓓ	35. ⓐ ⓑ ⓒ ⓓ	44. ⓐ ⓑ ⓒ ⓓ
9. ⓐ ⓑ ⓒ ⓓ	18. ⓐ ⓑ ⓒ ⓓ	27. ⓐ ⓑ ⓒ ⓓ	36. ⓐ ⓑ ⓒ ⓓ	45. ⓐ ⓑ ⓒ ⓓ

(1) Number of questions attempted : _____ (3) Marks scored : _____

(2) Number of questions correct : _____

For every correct answer award yourself 4 marks. For every incorrect answer deduct 1 mark.

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HINTS & SOLUTIONS

Mock Test Paper 1

1. **(c)** : Here, $R_{max} = \frac{u^2}{g} = \frac{1}{2}mu^2 \times \frac{2}{mg}$

But $\frac{1}{2}mu^2 = \frac{1}{2}kx^2$

$\therefore \quad R_{max} = \frac{1}{2}kx^2 \times \frac{2}{mg} = \frac{kx^2}{mg} = \frac{600 \times (0.05)^2}{0.015 \times 10} = 10 \text{ m}$

2. **(a)** : For solving the problem, we assume that observer is situated in the frame of pulley (non-inertial reference frame).

$m_1 g = w_1$

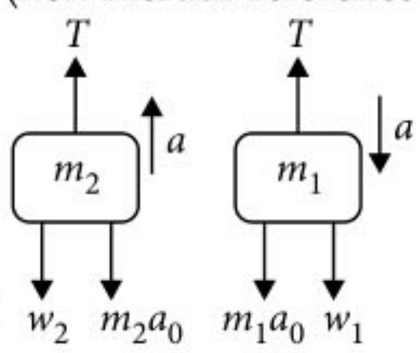
$m_2 g = w_2$

From force diagram,

$T - m_2 a_0 - w_2 = m_2 a$

or $T - m_2 g - w_2 = m_2 a \quad (\because a_0 = g)$

or $T - 2w_2 = m_2 a \quad \ldots$ (i)



From force diagram,

$m_1 a_0 + w_1 - T = m_1 a$

or $m_1 g + w_1 - T = m_1 a \quad (\because a_0 = g)$

or $2w_1 - T = m_1 a \quad \ldots$ (ii)

From eqs. (i) and (ii), we get

$T = \frac{4w_1 w_2}{w_1 + w_2}$

3. **(a)** : Time period, $T \propto p^a \rho^b E^c$

or $T = kp^a \rho^b E^c$

k is a dimensionless constant.

According to homogeneity of dimensions,

LHS = RHS

$\therefore \quad [T] = [ML^{-1}T^{-2}]^a [ML^{-3}]^b [ML^2T^{-2}]^c$

$[T] = [M^{a+b+c}][L^{-a-3b+2c}][T^{-2a-2c}]$

Comparing the powers, we obtain

$a + b + c = 0$

$-a - 3b + 2c = 0$

$-2a - 2c = 1$

On solving, we get

$a = -\frac{5}{6}, b = \frac{1}{2}, c = \frac{1}{3}$

4. **(a)** : Here, $u = 0, a = \frac{F}{m} = \frac{qE}{m}$

$v = u + at = 0 + \frac{qE}{m}t$

$\text{KE} = \frac{1}{2}mv^2 = \frac{mq^2E^2t^2}{2m^2} = \frac{E^2q^2t^2}{2m}$

5. **(d)** : If d_1 is the distance of point X on axial line and d_2 is distance of point Y on equatorial line, then

$B_1 = \frac{\mu_0}{4\pi}\frac{2M}{d_1^3}, B_2 = \frac{\mu_0}{4\pi}\frac{M}{d_2^3}$

As $B_1 = B_2$

$\therefore \quad \frac{\mu_0}{4\pi}\frac{2M}{d_1^3} = \frac{\mu_0}{4\pi}\frac{M}{d_2^3}$

$d_1^3 = 2d_2^3; \frac{d_1}{d_2} = 2^{1/3}$

6. **(b)** : Here, $n = 5, \gamma = 7/5, T_1 = 0°C, T_2 = 400°C$

$dU = \frac{nR\,dT}{\gamma - 1}$

$= \frac{5 \times 8.31 \times (400 - 0)}{(7/5) - 1} = 41550 \text{ J} = 41.55 \text{ kJ}$

7. **(c)** : Using angular momentum conservation,

$L_i = 0, L_f = mvR - I\omega$, so, $mvR = I\,\omega$

$\omega = \frac{mvR}{I} = \frac{50 \times 1 \times 2}{200} = \frac{1}{2}$

For one complete revolution,

$(v + \omega R)t = 2\pi R$

or $\left(1 + \frac{1}{2} \times 2\right)t = 2\pi \times 2 \Rightarrow t = 2\pi \text{ s}$

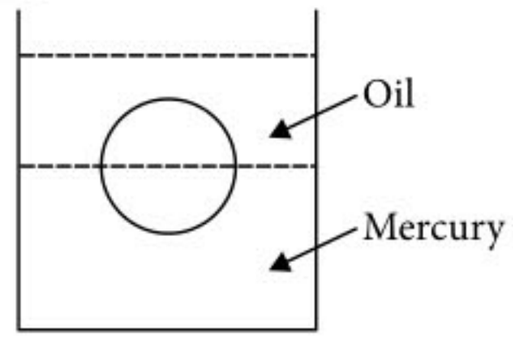
8. **(c)** : Weight = Buoyant force

$V\rho_m g = \frac{V}{2}\rho_{Hg} g + \frac{V}{2}\rho_{oil} g$

$\rho_m = \frac{\rho_{Hg} + \rho_{oil}}{2}$

$= \frac{13.6 + 0.8}{2}$

$= \frac{14.4}{2} = 7.2$



9. **(b)** : Higher is the temperature, greater is the most probable velocity.

10. **(d)** : $\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{25} + \frac{1}{100} = \frac{5}{100} = \frac{1}{20}$

$C_s = 20 \text{ μF} = 20 \times 10^{-6} \text{ F}$

$U_1 = \frac{1}{2}C_s V^2 = \frac{1}{2}(20 \times 10^{-6})(120)^2 = 144 \times 10^{-3} \text{ J}$

Charge on each capacitor,

$q_1 = q_2 = C_s \cdot V = 20 \times 120 = 2400 \text{ μC}$

In parallel, $C_p = C_1 + C_2$

$= 25 + 100 = 125 \text{ μF} = 125 \times 10^{-6} \text{ F}$

$\therefore \quad U_2 = \frac{Q^2}{2C_p} = \frac{[(2400 + 2400) \times 10^{-6}]^2}{2 \times 125 \times 10^{-6}}$

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$= 92.16 \times 10^{-3}$ J
Loss of energy $= U_1 - U_2$
$= (144 - 92.16) \times 10^{-3}$ J $= 51.84 \times 10^{-3}$ J $= 0.052$ J

11. (b) : Capacitor will work as open key. Therefore no current flows through resistance 4 Ω. The total resistance of circuit

$$= 2.8 + \frac{2\times3}{2+3} = 2.8 + 1.2 = 4\ \Omega$$

$\therefore$ Main current, $I = \frac{6}{4} = \frac{3}{2}$ A

Potential difference across A and B

$$= \frac{3}{2}\times1.2 = 1.8\ \text{V}$$

$\therefore$ Current through $2\ \Omega = \frac{1.8}{2} = 0.9$ A

12. (b) : As magnet is withdrawn from the coil, field into the coil decreases. To increase this field, current induced in the coil must be clockwise as seen by the withdrawing magnet.

13. (c) : For the lens, $\frac{1}{v} = \frac{1}{f} + \frac{1}{u} = \frac{1}{20} - \frac{1}{30} = \frac{1}{60}$

$v = 60$ cm
Therefore, to have an inverted image of the object, coincident with it, image should tend to form at centre of curvature of convex mirror. Therefore, distance of convex mirror from the lens = 60 – 10 = 50 cm.

14. (b) : For dark fringes,

$$Y_n = (2n-1)\frac{\lambda D}{2d} \Rightarrow Y_3 = \frac{5}{2}\frac{\lambda D}{d}$$

For bright fringes,

$$Y_n = \frac{n\lambda D}{d} \Rightarrow Y_5 = \frac{5\lambda D}{d}$$

$Y = Y_5 - Y_3$

$$Y = \frac{5\lambda}{2}\frac{D}{d} = \frac{5\times6.5\times10^{-7}\times1}{2\times10^{-3}}$$

$= 1.625 \times 10^{-3}$ m $= 1.63$ mm

15. (d) : Here, power of the bulb, $P = 100$ W
Supply voltage, $\varepsilon = 230$ V
Let R be the resistance of the bulb.

$$\text{As } P = \frac{\varepsilon^2}{R} \Rightarrow R = \frac{\varepsilon^2}{P} = \frac{(230)^2}{100} = 529\ \Omega$$

Changed supply voltage, $\varepsilon' = 115$ V
Heat and light energy produced by the bulb in 20 min

$$= \frac{\varepsilon'^2 t}{R} = \frac{115^2\times20\times60}{529} = 30{,}000\ \text{J} = 30\ \text{kJ}$$

16. (b) : In equilibrium,
weight of the suspended body = stretching force.
$\therefore$ At the earth's surface, $mg = k \times x$
At a height h, $mg' = k \times x'$

$$\frac{g'}{g} = \frac{x'}{x} = \frac{R_e^2}{(R_e+h)^2} = \frac{(6400)^2}{(6400+1600)^2} = \left(\frac{6400}{8000}\right)^2 = \frac{16}{25}$$

$$x' = \frac{16}{25}\times x = \frac{16}{25}\times1\ \text{cm} = 0.64\ \text{cm}$$

17. (b) : As $V_C = \varepsilon(1 - e^{-t/RC})$

or $1 - e^{-t/RC} = \frac{V_C}{\varepsilon} = \frac{120}{200} = \frac{3}{5}$

or $e^{t/RC} = 2.5$ or $\log e^{t/RC} = \log_e 2.5$

or $\frac{t}{RC} = 2.3026\log_{10}2.5 = 0.92$

or $R = \frac{t}{0.92C} = \frac{5}{0.92\times2\times10^{-6}} = 2.7\times10^6\ \Omega$

18. (a) : $\varepsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}(50t^2 + 4) = -100t$

When $t = 2$ s, $|\varepsilon| = 200$ V
Induced current at $t = 2$ s,

$$I = \frac{|\varepsilon|}{R} = \frac{200}{400} = 0.5\ \text{A}$$

19. (d) : Frequency remains unchanged with change of medium.

$$\mu\ (\text{refractive index}) = \frac{c}{v} = \frac{1/\sqrt{\varepsilon_0\mu_0}}{1/\sqrt{\varepsilon\mu}} = \sqrt{\varepsilon_r\mu_r}$$

Since, μ_r is very close to 1, $\mu = \sqrt{\varepsilon_r} = \sqrt{4} = 2$

Thus, $\lambda_{\text{medium}} = \frac{\lambda}{\mu} = \frac{\lambda}{2}$

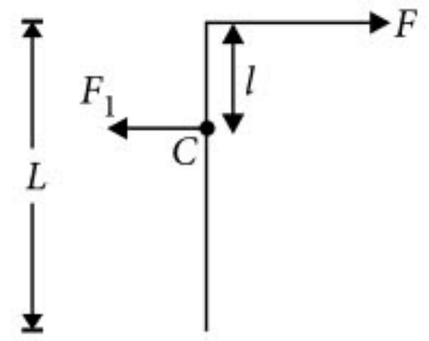
20. (b) : $Y = \frac{F}{A}\times\frac{L}{\Delta L}$

The breaking strength $F \propto A$

$$\therefore \quad \frac{F_2}{F_1} = \frac{A_2}{A_1} = \frac{\pi(D_2^2/4)}{\pi(D_1^2/4)} = \frac{D_2^2}{D_1^2}$$

$$\text{or} \quad D_2 = D_1\left(\frac{F_2}{F_1}\right)^{1/2} = 3\left(\frac{600}{150}\right)^{1/2} = 6\ \text{cm}$$

21. (b) : Let L be the length of the rod of mass m, with centre of mass at C. Suppose F_1 is the magnitude of other force. Let $F_1 > F$.



$\therefore$ $F_1 - F = ma$ or $F_1 = F + ma$
As the rod moves translationally and there is no rotation, therefore, net torque about C must be zero.

$$\therefore \quad F\left(\frac{L}{2}\right) = F_1\left(\frac{L}{2} - l\right) = (F+ma)\left(\frac{L}{2} - l\right)$$

$$F\left(\frac{L}{2}\right) = F\left(\frac{L}{2}\right) - Fl + ma\frac{L}{2} - mal$$

$$ma\frac{L}{2} = l(F+ma)$$

$$\therefore \quad L = \frac{2(F+ma)l}{ma}$$

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22. (b) : $W = \frac{1}{2}K\left(x_2^2 - x_1^2\right)$

$= \frac{1}{2}K(20^2 - 10^2) = 150 \text{ kJ}$

which is less than work done in stretching it from 20 cm to 30 cm.

$$\left[\text{viz. } \frac{1}{2}K(30^2 - 20^2) = 250 \text{ kJ}\right]$$

23. (b) : Total average energy density of electromagnetic wave is

$$< u > = \frac{1}{2}\varepsilon_0 E_{rms}^2 + \frac{1}{2\mu_0}B_{rms}^2$$

$$= \frac{1}{2}\varepsilon_0 E_{rms}^2 + \frac{1}{2\mu_0}\left(\frac{E_{rms}^2}{c^2}\right) \qquad \left(\because B_{rms} = \frac{E_{rms}}{c}\right)$$

$$= \frac{1}{2}\varepsilon_0 E_{rms}^2 + \frac{1}{2\mu_0}E_{rms}^2\varepsilon_0\mu_0$$

$$= \frac{1}{2}\varepsilon_0 E_{rms}^2 + \frac{1}{2}\varepsilon_0 E_{rms}^2 = \varepsilon_0 E_{rms}^2$$

$= (8.85 \times 10^{-12}) \times (720)^2 = 4.58 \times 10^{-6} \text{ J m}^{-3}$

24. (c) : Here, $A_2 = 2A_1$

$\because$ Intensity $\propto$ (Amplitude)^2

$$\therefore \quad \frac{I_2}{I_1} = \left(\frac{A_2}{A_1}\right)^2 = \left(\frac{2A_1}{A_1}\right)^2 = 4 \; ; \; I_2 = 4I_1$$

Maximum intensity, $I_m = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2$

$$= \left(\sqrt{I_1} + \sqrt{4I_1}\right)^2 = \left(3\sqrt{I_1}\right)^2 = 9I_1 \text{ or } I_1 = \frac{I_m}{9} \qquad \ldots(i)$$

Resultant intensity, $I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$

$= I_1 + 4I_1 + 2\sqrt{I_1(4I_1)}\cos\phi$

$= 5I_1 + 4I_1\cos\phi = I_1 + 4I_1 + 4I_1\cos\phi = I_1 + 4I_1(1 + \cos\phi)$

$$= I_1 + 8I_1\cos^2\frac{\phi}{2} \qquad \left(\because 1 + \cos\phi = 2\cos^2\frac{\phi}{2}\right)$$

$$= I_1\left(1 + 8\cos^2\frac{\phi}{2}\right)$$

Putting the value of I_1 from eq. (i), we get

$$I = \frac{I_m}{9}\left(1 + 8\cos^2\frac{\phi}{2}\right)$$

25. (a) : Here, $u_o = -5$ cm, $f_o = 4$ cm

$f_e = 10$ cm, $D = 20$ cm

According to lens formula,

$$\frac{1}{v_o} = \frac{1}{4} + \frac{1}{-5} = \frac{1}{4} - \frac{1}{5} = \frac{1}{20}$$

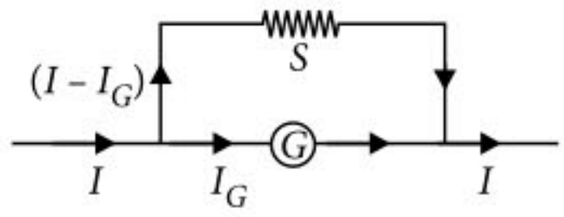
$v_o = 20$ cm

Magnification, $M = \frac{v_o}{|u_o|}\left(1 + \frac{D}{f_e}\right) = \frac{20}{5}\left(1 + \frac{20}{10}\right) = 12$

26. (b) : As shunt is a small resistance S in parallel with a galvanometer (of resistance G) as shown in figure.

$(I - I_G)S = I_G G$

$$S = \frac{I_G G}{(I - I_G)}$$



Here, $I_G = \frac{5}{100}I$

$$\therefore \quad S = \frac{\frac{5}{100}IG}{I - \frac{5}{100}I} = \frac{G}{19}$$

27. (c) : Resistance of the circuit,

$R = R_1 + R_2 = 40\ \Omega + 40\ \Omega = 80\ \Omega$

Impedance of the circuit,

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(80)^2 + (100 - 40)^2}$$

$$= \sqrt{(80)^2 + (60)^2} = 100\ \Omega$$

Power factor, $\cos\phi = \frac{R}{Z} = \frac{80}{100} = 0.8$

28. (c) : Monoatomic gas $C_V = \frac{3}{2}R$

This value is same for high temperature also.

In case of diatomic gas

$C_V = \frac{5}{2}R$ (at low temperature)

Also, $C_V > \frac{5}{2}R$ (at high temperature due to vibrational kinetic energy)

29. (c) : As $v^2 - v_0^2 = 2gh$, $0 - (10)^2 = 2(-10)\,h$

or $h = 5$ m

Also, $v = v_0 + at$, $0 = 10 + (-10)\,t$

or $t = 1$ s

Height covered in time $t/2$, *i.e.*, (1/2 s),

$$h' = v_0 t + \frac{1}{2}(-g)t^2 = 10 \times \frac{1}{2} - \frac{1}{2} \times 10 \times \left(\frac{1}{2}\right)^2$$

$= 3.75$ m $= (3/4)\,h$

30. (c) : As $\theta_1 = \omega_0 t + \frac{1}{2}\alpha t^2 = 0 + \frac{1}{2}\alpha(2)^2 = 2\alpha$

$$(\theta_1 + \theta_2) = \omega_0 t + \frac{1}{2}\alpha t^2 = 0 + \frac{1}{2}\alpha(4)^2 = 8\alpha$$

Thus, $\theta_2 = 6\alpha$ or $\frac{\theta_2}{\theta_1} = 3$

31. (c) : Mass of $\left(\frac{l}{4}\right)$ length of the chain $= \frac{m}{4}$

The weight of this part of the chain acts as its *CG* which is at a distance $\left(\frac{l}{8}\right)$ from the edge of the table.

Work done $= \left(\frac{m}{4}\right)g\left(\frac{l}{8}\right) = \frac{mgl}{32}$

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32. (c) : As $R_D = \frac{V_D^2}{P_D} = \frac{(0.5\text{ V})^2}{0.1\text{ W}} = 2.5\ \Omega$

$I_D = \frac{V_D}{R_D} = 0.2\text{ A}$

Total resistance required in the circuit,

$R_{eq} = \frac{V}{I_D} = \frac{1.5}{0.2} = 7.5\ \Omega$

Resistance of the series resistor, $R = R_{eq} - R_D$
$= 7.5 - 2.5 = 5\ \Omega$

33. (c) : As $\frac{N_X}{N_Y} = \frac{1}{15}$, $N_X + N_Y = 16N_X$

Thus, $\frac{N_X}{N_X + N_Y} = \frac{1}{16}$

or $N_X = \frac{1}{16}(N_X + N_Y) = \frac{1}{2^4}(N_X + N_Y)$

Age of the rock = number of half-lives of isotope X passed
$= 4 \times 50$ years $= 200$ years

34. (a) : Here, $\lambda = 6.2 \times 10^{-6}$ m, $\phi_0 = 0.1$ eV

Energy of the incident photon, $E = h\upsilon = \frac{hc}{\lambda}$

or $E = \frac{(6.6\times10^{-34})(3\times10^{8})}{6.2\times10^{-6}}$ J

$= \frac{6.6\times3\times10^{-26}}{(6.2\times10^{-6})(1.6\times10^{-19})}$ eV $= 0.2$ eV

As $E = K + \phi_0$, $K = E - \phi_0$

$= 0.2$ eV $- 0.1$ eV $= 0.1$ eV

35. (b) : $\upsilon = \frac{1}{2\pi}\sqrt{\frac{k}{m}} = \frac{1}{2\pi}\sqrt{\frac{200}{0.2}} = 5$ Hz

In equilibrium, $kx = mg$

or $x = \frac{mg}{k} = \frac{0.2\times10}{200} = 0.01$ m

When mass is raised till the spring is unstretched, the work $= \frac{1}{2}kx^2 = mgx$

When the mass is released from the unstretched position of spring, then total work done

$mgx' = (mgx) + \frac{1}{2}kx^2 = 2mgx$

or $x' = 2x = 2 \times 0.1 = 0.02$ m

As υ of spring is independent of g so that the frequency of oscillation will be the same as that on the earth.

36. (c) : Here, $Y = 10^{-5}\sin\left[100t - \frac{x}{10}\right]$

Comparing it with, standard equation of wave motion

$Y = r\sin\left[\frac{2\pi}{T}t - \frac{2\pi}{\lambda}x\right]$

$\frac{2\pi}{T} = 100$, $T = \frac{2\pi}{100} = \frac{\pi}{50}$ s ; $\frac{2\pi}{\lambda} = \frac{1}{10}$, $\lambda = 20\pi$

Velocity, $v = \frac{\lambda}{T} = \frac{20\pi}{\pi/50} = 1000\text{ m s}^{-1}$

37. (a) : On the surface of earth, the force on a mass of 1 kg is

$F = \frac{GMm}{R^2} = \frac{GM\times1}{R^2} = 10$ ... (i)

When the radius of the satellite, $r = 3R/2$, the force on the satellite is

$F = \frac{GMm'}{r^2} = \frac{GM\times100}{(3/2)^2 R^2}$

$= \frac{10\times4\times100}{9} = 4.44\times10^2$ N (Using (i))

38. (d) : The far point of 6.0 m tell us that the focal length of the lens is $f = -6.0$ m, $u = -18$ m and $h = 2$ m

Using, $\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \Rightarrow \frac{1}{v} = \frac{1}{f} + \frac{1}{u} = \frac{1}{-6.0} - \frac{1}{18.0}$

$\Rightarrow v = -4.5$ m

$\therefore$ The image size,

$h' = h\left(\frac{-v}{u}\right) = 2\times\left(-\frac{-4.5}{18.0}\right) = 0.50$ m

39. (a) : Here, displacement $= 8.4 + 2 = 10.4$ km

Total time taken $= \frac{1}{2} + \frac{8.4}{70} = 0.62$ h

Average velocity $= \frac{\text{Displacement}}{\text{Total time taken}}$

$= \frac{10.4\text{ km}}{0.62\text{ h}} = 16.8\text{ km h}^{-1}$

40. (c) : Let υ be frequency of standard fork. The frequency of A, $\upsilon_A = \upsilon + \frac{2}{100}\upsilon$

and the frequency of B, $\upsilon_B = \upsilon - \frac{3}{100}\upsilon$

According to question,

$\upsilon_A - \upsilon_B = 6$

$\therefore \left(\upsilon + \frac{2}{100}\upsilon\right) - \left(\upsilon - \frac{3}{100}\upsilon\right) = 6$

or $\frac{5}{100}\upsilon = 6$ or $\upsilon = \frac{600}{5} = 120$ Hz

The frequency of A

$\upsilon_A = \left(\upsilon + \frac{2}{100}\upsilon\right) = 120 + \frac{2}{100}\times120 = 122.4$ Hz

41. (a) : Poisson's ratio $= \frac{\text{Lateral strain}}{\text{Longitudinal strain}}$

Longitudinal strain $= \frac{\text{Lateral strain}}{\text{Poisson's ratio}} = \frac{0.01\times10^{-3}}{0.4}$ ... (i)

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$$\text{Young's modulus, } Y = \frac{\text{Normal stress}}{\text{Longitudinal strain}}$$

$$Y = \frac{F}{A\times\left(\frac{0.01\times10^{-3}}{0.4}\right)} \qquad \text{(Using (i))}$$

$$= \frac{100\times0.4}{0.025\times0.01\times10^{-3}}\ \text{N m}^{-2} = 1.6\times10^{8}\ \text{N m}^{-2}$$

42. (c) : Energy of incident photon, $E = \frac{hc}{\lambda}$

$$E = \frac{6.6\times10^{-34}\times3\times10^{8}}{2\times10^{-7}}$$

$$= 9.9\times10^{-19}\ \text{J} = \frac{9.9\times10^{-19}}{1.6\times10^{-19}}\ \text{eV} = 6.2\ \text{eV}$$

$K_{max} = eV_s = e\times 2.5\ \text{V} = 2.5\ \text{eV}$

According to Einstein's photoelectric equation

$$K_{max} = \frac{hc}{\lambda} - \phi_0$$

where the symbols have their usual meanings.

$$\text{or} \quad \phi_0 = \frac{hc}{\lambda} - K_{max} = 6.2\ \text{eV} - 2.5\ \text{eV} = 3.7\ \text{eV}$$

Threshold frequency, $\upsilon_0 = \frac{\phi_0}{h}$

$$\upsilon_0 = \frac{3.7\times1.6\times10^{-19}}{6.6\times10^{-34}} = 0.9\times10^{15}\ \text{Hz} = 9\times10^{14}\ \text{Hz}$$

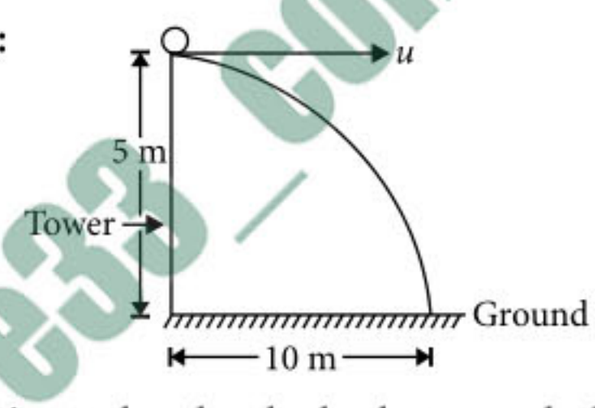
43. (d) : When potentiometer is connected between A and B, then it measures only ε_1 and when connected between A and C, then it measures $\varepsilon_1 - \varepsilon_2$.

$$\therefore \quad \frac{\varepsilon_1}{\varepsilon_1-\varepsilon_2} = \frac{l_1}{l_2},\ \frac{\varepsilon_1-\varepsilon_2}{\varepsilon_1} = \frac{l_2}{l_1}$$

$$\text{or} \quad 1-\frac{\varepsilon_2}{\varepsilon_1} = \frac{100}{300} \text{ or } \frac{\varepsilon_2}{\varepsilon_1} = 1-\frac{1}{3}$$

$$\text{or} \quad \frac{\varepsilon_2}{\varepsilon_1} = \frac{2}{3} \text{ or } \frac{\varepsilon_1}{\varepsilon_2} = \frac{3}{2}$$

44. (c) :



Let t be time taken by the body to reach the ground.

$$\therefore \quad H = \frac{1}{2}gt^2 \text{ or } t = \sqrt{\frac{2H}{g}} = \sqrt{\frac{2\times5}{10}} = 1\ \text{s}$$

$R = ut$ or $10 = u\times1$ or $u = 10\ \text{m s}^{-1}$

45. (c)

Mock Test Paper 2

1. (a) : As $\lambda = \frac{h}{p},\ \frac{d\lambda}{\lambda} = \frac{dp}{p}$

According to question,

$$dp = p,\ \frac{d\lambda}{\lambda} = 0.5\% = \frac{0.5}{100},\ \text{Initial moment} = p'\ \text{(say)}$$

$$\text{So,} \quad \frac{0.5}{100} = \frac{p}{p'} \text{ or } p' = 200\,p$$

2. (b) : The binding (or ionization) energy of the hydrogen atom is

$13.6\ \text{eV} = 2.18\times10^{-18}\ \text{J}$

Since the average molecular energy of a gas whose absolute temperature T is equal to $\frac{3}{2}kT$, here

$$\frac{3}{2}kT, = E$$

$$\text{or } T = \frac{2E}{3k} = \frac{(2)(2.18\times10^{-18}\ \text{J})}{(3)(1.38\times10^{-23}\ \text{J K}^{-1})} = 1.05\times10^{5}\ \text{K}$$

3. (d) : Given, $A = 1.0\ \text{m} \pm 0.2\ \text{m}$, $B = 2.0\ \text{m} \pm 0.2\ \text{m}$

$$x = \sqrt{AB} = \sqrt{1.0\times2.0} = 1.414\ \text{m}$$

Rounding-off to two significant digits,

$$x = \sqrt{AB} = 1.4\ \text{m}$$

Now, $\frac{\Delta x}{x} = \frac{1}{2}\left[\frac{\Delta A}{A} + \frac{\Delta B}{B}\right]$

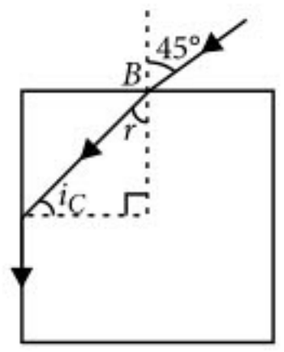
$$= \frac{1}{2}\left[\frac{0.2}{1.0} + \frac{0.2}{2.0}\right] = \frac{0.6}{2\times2}$$

$$\Delta x = \frac{0.6}{2\times2}\times1.414 = 0.2121 \simeq 0.2\ \text{m}$$

4. (c) : As $r + i_C = 90°$, $r = (90° - i_C)$

Apply Snell's law at point B

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin 45°}{\sin(90°-i_C)} = \frac{1}{\sqrt{2}\cos i_C}$$



$$\text{As} \quad \mu = \frac{1}{\sin i_C},\ \sin i_C = \sqrt{2}\cos i_C$$

$$\text{or} \quad \tan i_C = \sqrt{2}\ \text{, where } \sin i_C = \sqrt{\frac{2}{3}}$$

$$\text{or} \quad \mu = \frac{1}{\sin i_C} = \sqrt{\frac{3}{2}}$$

5. (a) : Since the angle of repose is at least 25°,

$\mu_s \geq \tan 25° = 0.47$

6. (a) : As, $\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$

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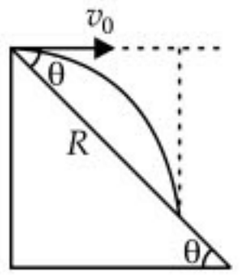
$$\therefore \quad \frac{Q_2}{6\times10^4}=\frac{127+273}{227+273}=\frac{400}{500}$$

$$Q_2=\frac{4}{5}\times6\times10^4=4.8\times10^4\,\text{cal}$$

$$\therefore \quad W=Q_1-Q_2$$
$$=6\times10^4-4.8\times10^4=1.2\times10^4\,\text{cal}$$

7. (a) : Range of the projectile on an inclined plane (down the plane) is,



$$R=\frac{u^2}{g\cos^2\beta}[\sin(2\alpha+\beta)+\sin\beta]$$

Here, $u=v_0$, $\alpha=0$ and $\beta=\theta$

$$\therefore \quad R=\frac{2v_0^2\sin\theta}{g\cos^2\theta}$$

Now $x=R\cos\theta=\dfrac{2v_0^2\tan\theta}{g}$

and $y=-R\sin\theta=-\dfrac{2v_0^2\tan^2\theta}{g}$

8. (a) : Let x be compression of spring when weight mg is placed on the pan. Then

$kx=mg$

or $\quad x=\dfrac{mg}{k}=\dfrac{2\times10}{200}=0.10\text{ m}$

$$\omega=\sqrt{\frac{k}{m}}=\sqrt{\frac{200}{2}}=10\text{ rad s}^{-1}$$

If A is the amplitude of oscillation of the mass, then the restoring force, $m\omega^2 A\geq mg$ or $A\geq\dfrac{g}{\omega^2}$.

In this situation, the mass will move up with acceleration, detached from the pan. Hence,

$A\geq\dfrac{g}{(k/m)}$ or $A\geq\dfrac{10}{(200/2)}=0.10\text{ m}=10\text{ cm}$

$A_{\min}=10$ cm

9. (a) : The force of interaction $=F=k\dfrac{q(Q-q)}{d^2}$

For F to be maximum, $\dfrac{dF}{dq}=0=(Q-2q)\dfrac{k}{d^2}$

or $\quad q=\dfrac{Q}{2}$

10. (c) : Intensity at the centre of the pattern will be zero, if path difference at the centre is $\lambda/2$. Now, the path difference introduced by glass plate of thickness is $(\mu-1)t$

$$\therefore \quad (\mu-1)t=\frac{\lambda}{2} \text{ or } t=\frac{\lambda}{2(\mu-1)}$$

11. (b) : Let v_w be velocity of water and v_b be the velocity of motor boat in still water. If x is the distance covered, then as per question

$x=(v_b+v_w)\times6=(v_b-v_w)\times10$

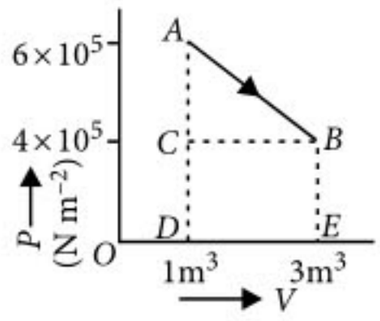
On solving, $v_w=v_b/4$

$\therefore \quad x=(v_b+v_b/4)\times6=7.5\,v_b$

Time taken by motor boat to cross the same distance in still water is

$$t=\frac{x}{v_b}=\frac{7.5v_b}{v_b}=7.5\text{ h}$$

12. (d) : According to question, the figure can be drawn as shown.



Now, work done by the system
= Area under P-V diagram
= Area of rectangle $BCDE$ + area of ΔABC

$$=4\times10^5\times2+\frac{2\times10^5\times2}{2}$$

$\Rightarrow \quad W=10\times10^5$ J

13. (c) : With each rotation, charge Q crosses any fixed point P near the ring.

Number of rotations per second $=\omega/2\pi$.

$\therefore$ Charge crossing P per second = current $=\dfrac{Q\omega}{2\pi}$

14. (a) : A closed, current-carrying loop of any shape placed in any uniform magnetic field, experiences no force.

15. (d) : Here, $y_1=4\sin600\pi t$

Comparing with equation $y_1=a_1\sin2\pi\upsilon_1 t$

$$a_1=4,\ \upsilon_1=\frac{600\pi}{2\pi}=300\text{ Hz}$$

$y_2=5\sin608\pi t$

Comparing with equation

$y_2=a_2\sin2\pi\upsilon_2 t$

$$a_2=5,\ \upsilon_2=\frac{608\pi}{2\pi}=304\text{ Hz}$$

Number of beat/sec $=\upsilon_2-\upsilon_1=304-300=4$

Intensity ratio,

$$\frac{I_{\max}}{I_{\min}}=\frac{(a_1+a_2)^2}{(a_1-a_2)^2}=\frac{(4+5)^2}{(4-5)^2}=\frac{81}{1}$$

16. (b) : When a charged capacitor is disconnected from the cell to which it was connected, its charge remains constant. Any change in the capacitor may change its capacitance, its stored energy and its potential difference.

17. (a) : When two nuclei combine to form a single nucleus, and energy is released, we have fusion reaction. If a single nucleus splits into two, it is fission. The possibility of fusion is more for light elements and fission takes place for heavy elements.

Out of the choices given for fusion, only A and B are light elements and D and E are heavy elements. Therefore, $A+B\rightarrow C+Q$ is correct. The possibility of fission is only for F and not for C. Therefore, $F\rightarrow D+E+Q$ is the correct choice.

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18. (b) : Diode D_1 is reverse-biased and as such no current flows through it and consequently resistance of 3 Ω is ineffective. Only diode D_2 conducts as it is forward-biased.

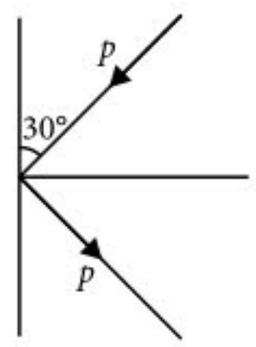
Thus, $I = \frac{V}{R} = \frac{12\text{ V}}{2\,\Omega + 4\,\Omega} = 2\text{ A}$

19. (a) : Change in momentum

$\Delta p = 2mu \sin 30°$

$= 2 \times 0.1 \times 10 \times \frac{1}{2} = 1\text{ kg m s}^{-1}$

$\therefore \quad F_{av} = \frac{\Delta p}{\Delta t} = \frac{1}{0.1} = 10\text{ N}$



20. (c) : When a body of mass M slides down an inclined plane, then $v = \sqrt{2gh}$

When it is in the form of ring and rolls down then

$$v_{ring} = \sqrt{\frac{2gh}{\left(1 + \frac{K^2}{R^2}\right)}} = \sqrt{\frac{2gh}{1+1}} = \frac{\sqrt{2gh}}{\sqrt{2}} = \frac{v}{\sqrt{2}}$$

21. (b) : On reflection from a denser medium, there is a phase reversal of 180°.

New amplitude $= \frac{2}{3} \times 0.6 = 0.4$

$\therefore$ Equation of reflected wave is

$$y = 0.4 \sin 2\pi\left[t + \frac{x}{2} + 180°\right]$$

$$= -0.4 \sin 2\pi(t + x/2)$$

22. (d) : Current can flow in a circuit or part of a circuit only when it has a return path, *i.e.*, it can return to its starting point. Here, current flowing from X to Y cannot return to X.

23. (a) : As, $\eta = \frac{\text{Output power}}{\text{Input power}}$

or, $\eta = \frac{P_0}{V_{in} I_{in}} = \frac{100}{220 \times 0.5}$

$= 0.909 = 90.9\% \simeq 90\%$

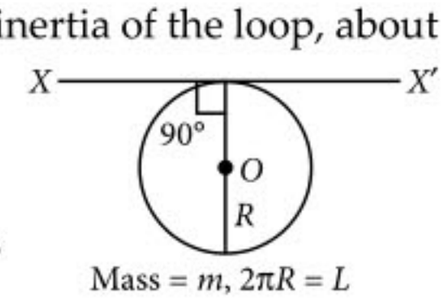
24. (d) : Let I denote moment of inertia of the loop, about the axis XX'.

$\therefore \quad I = \frac{mR^2}{2} + mR^2 = \frac{3}{2}mR^2$

Now m = mass of loop or $m = L\rho$

Again $2\pi R = L$ or $R = \frac{L}{2\pi}$

$\therefore \quad I = \frac{3}{2}(L\rho)\left(\frac{L}{2\pi}\right)^2$ or $I = \frac{3L^3\rho}{8\pi^2}$



25. (c) : Gravitational force remains constant on the falling spherical ball. It is represented by straight line P. The viscous force ($F = 6\pi\eta rv$) increases as the velocity increases with time. Hence, it is represented by curve Q.

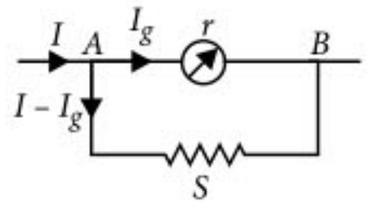
Net force = gravitational force – viscous force. As viscous force increases, net force decreases and finally becomes zero. Then the body falls with a constant terminal velocity. It is thus represented by curve R.

26. (c) : Here, $I_g = 10\text{ mA} = 0.01\text{ A}$

$r = 1\,\Omega \quad I = 1\text{ A}$

$V_A - V_B = I_g r = (I - I_g)S$

$$S = \frac{I_g r}{I - I_g} = \frac{0.01\text{ A} \times 1\,\Omega}{1\text{ A} - 0.01\text{ A}} = \frac{1}{99}\,\Omega$$



27. (c) : Focal length of the planoconvex lens with plane surface silvered = (15/2) cm. As this acts as a converging mirror, $f = -15/2$ cm, $u = -20$ cm, from $\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$, So,

$$\frac{1}{v} = \frac{2}{-15} + \frac{1}{20}$$

$v = -12$ cm (left of the system)

28. (c) : As $K = h\upsilon - \phi_0$,

$K_1 = 1\text{ eV} - 0.5\text{ eV} = 0.5\text{ eV}$, and

$K_2 = 2.5\text{ eV} - 0.5\text{ eV} = 2\text{ eV}$,

$$\frac{K_1}{K_2} = \frac{0.5\text{ eV}}{2\text{ eV}} = \frac{1}{4} \quad \text{or} \quad \frac{v_1}{v_2} = \sqrt{\frac{1}{4}} = \frac{1}{2} = 1:2$$

29. (b) : As both the balls are of same size, force of buoyancy on each is same. Therefore, in equilibrium,

$F + F = m_1 g + m_2 g$

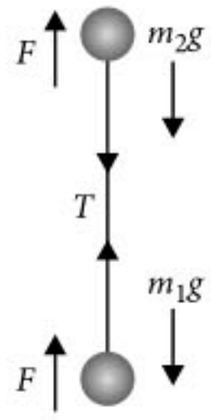
or $\quad F = (m_1 + m_2)\frac{g}{2}$

Considering the equilibrium of lower ball,

$T + F = m_1 g$

$$T = m_1 g - (m_1 + m_2)\frac{g}{2}$$

$$T = (m_1 - m_2)\frac{g}{2}$$



30. (a) : The resistance in the middle plays no part in the charging process of C, as it does not alter either the potential difference across the RC combination or the current through it.

31. (c) : $E = 11\text{ eV} = 11 \times 1.6 \times 10^{-19} = h\upsilon$

or $\quad \upsilon = \frac{11 \times 1.6 \times 10^{-19}}{h} = \frac{11 \times 1.6 \times 10^{-19}}{6.62 \times 10^{-34}} = 2.65 \times 10^{15}\text{ Hz}$

It comes in range of ultraviolet region.

32. (a) : As intensity of transmitted light, $I = I_0 \cos^2\theta$ and the average value of $\cos^2\theta = \frac{1}{2}$, $I = \frac{I_0}{2}$.

Intensity of light which is not transmitted

$$= I_0 - \frac{I_0}{2} = \frac{I_0}{2}$$

33. (a) : Each electron interacts not only with positively charged nucleus (which provides the central force) but also with all other electrons, *i.e.*, we have to take into account electron-electron interaction. Thus, the electrons are not subject to a central force.

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34. (c) : As $A_v = \frac{V_o}{V_i} = \beta\left(\frac{R_{out}}{R_{in}}\right)$

$\Rightarrow V_o = V_i \beta\left(\frac{R_{out}}{R_{in}}\right)$

$= (1\times10^{-3}\text{ V})(100)\left(\frac{10\text{ k}\Omega}{1\text{ k}\Omega}\right) = 1\text{ V}$

35. (b) : According to conservation of energy,

$W = \Delta KE + \Delta PE + W_f$

Since the length of the ramp, $s = 15$ m and its height is $h = 2$ m,

$W = F.s = (100\text{ N})\ (15\text{ m}) = 1500\text{ J}$

$\Delta KE = KE_{final} - KE_{initial}$

$\frac{1}{2}mv^2 = \left(\frac{1}{2}\right)(30\text{ kg})(2\text{ m s}^{-1})^2 = 60\text{ J}$

$\Delta PE = PE_{final} - PE_{initial}$

$= mgh = (30\text{ kg})\ (9.8\text{ m s}^{-2})\ (2\text{ m}) = 588\text{ J}$

The work done against friction is therefore

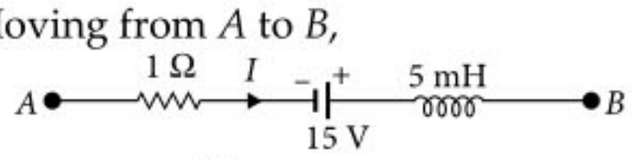
$W_f = W - \Delta KE - \Delta PE$

$= 1500\text{ J} - 60\text{ J} - 588\text{ J} = 852\text{ J}$

If F_f is the frictional force, then $W_f = F_f s$

and $F_f = \frac{W_f}{s} = \frac{852\text{ J}}{15\text{ m}} = 56.8\text{ N} \approx 57\text{ N}$

36. (b) : Moving from A to B,



$V_A - V_B = IR - V + L\frac{dI}{dt}$

$V_A - V_B = 1\times5 - 15 + 5\times10^{-3}\ (-10^3) = -15\text{ V}$

[$\frac{dI}{dt}$ is negative as I is decreasing]

or $V_B - V_A = 15\text{ V}$

37. (a) : As, $B = \frac{E}{c} = \frac{6.3}{3\times10^8} = 2.1\times10^{-8}\text{ T}$

Since B is perpendicular to the direction of propagation of EM waves as well as the electric field. So

$\vec{B} = 2.1\times10^{-8}\,\hat{k}\,\text{T}$

38. (b) : Moon is moving under the combined gravitatinal pull acting on it due to Earth and the Sun. So force on the moon will not be central.

39. (d) : Total magnetic flux passing through whole of the x - y plane will be zero.

The magnetic lines form a closed loop. The number of lines moving downwards in x - y plane will be same in number to that coming from upwards of the plane. Net flux will therefore be zero.

40. (c) : We know activity of the sample is $R = \lambda N$, $n = \lambda N$, or $\lambda = (n/N)\ \text{s}^{-1}$

Half life, $T_{1/2} = \frac{0.693}{\lambda} = \frac{0.693N}{n}\text{ s}$

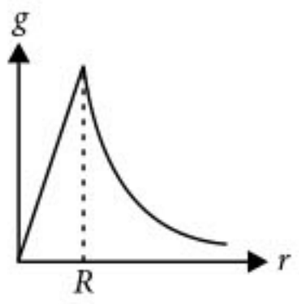
41. (a) : In n-type semiconductor fermi level indicates extra electron energy levels due to impurity.

42. (a) : The acceleration due to gravity at a depth d below the surface of earth is

$$g' = g\left(1-\frac{d}{R}\right) = g\left(\frac{R-d}{R}\right) = g\frac{r}{R} \qquad ...(i)$$

where, $R - d = r$ = distance of location from the centre of the earth. When $r = 0$, $g' = 0$.

From (i) $g' \propto r$, till $r = R$, for which $g' = g$



For $r > R$, $g' = \frac{gR^2}{(R+h)^2} = \frac{gR^2}{r^2}$

or $g' \propto \frac{1}{r^2}$

Here $R + h = r$

Therefore, the variation of g with distance r from centre of earth will be as shown in figure.

43. (b) : For a closed system, the total mass of gas or the number of moles remains constant.

For two vessels,

$P_1V = n_1RT_1$, $P_2V = n_2RT_2$,

After joining the two vessels,

$P(2V) = (n_1 + n_2)RT$

or $\frac{P}{T} = \frac{1}{2}\left(\frac{n_1R}{V} + \frac{n_2R}{V}\right) = \frac{1}{2}\left(\frac{P_1}{T_1} + \frac{P_2}{T_2}\right)$

44. (d)

45. (b) : Let V be the volume of the iceberg and x be the volume of iceberg out of sea water. The iceberg is floating in sea water, then

$V \times 0.92 \times g = (V - x) \times 1.03 \times g$

or $1.03\ V - 0.92\ V = 1.03x$ or $\frac{x}{V} = \frac{0.11}{1.03}$

$\therefore$ % fraction of the volume of iceberg above the level of sea water

$= \frac{x}{V}\times100 = \frac{0.11\times100}{1.03} \approx 11\%$

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ANSWER KEYS (Unit Tests)

Unit Test 1

1.	(d)	**2.**	(c)	**3.**	(c)	**4.**	(b)	**5.**	(c)	**6.**	(d)	**7.**	(d)	**8.**	(c)	**9.**	(a)
10.	(b)	**11.**	(c)	**12.**	(c)	**13.**	(c)	**14.**	(d)	**15.**	(d)	**16.**	(c)	**17.**	(c)	**18.**	(b)
19.	(c)	**20.**	(a)	**21.**	(b)	**22.**	(b)	**23.**	(d)	**24.**	(c)	**25.**	(c)	**26.**	(a)	**27.**	(c)
28.	(b)	**29.**	(c)	**30.**	(c)	**31.**	(c)	**32.**	(d)	**33.**	(b)	**34.**	(d)	**35.**	(b)	**36.**	(b)
37.	(b)	**38.**	(a)	**39.**	(b)	**40.**	(a)	**41.**	(a)	**42.**	(c)	**43.**	(c)	**44.**	(a)	**45.**	(a)

Unit Test 2

1.	(d)	**2.**	(c)	**3.**	(d)	**4.**	(b)	**5.**	(a)	**6.**	(d)	**7.**	(a)	**8.**	(c)	**9.**	(c)
10.	(a)	**11.**	(a)	**12.**	(c)	**13.**	(d)	**14.**	(d)	**15.**	(d)	**16.**	(b)	**17.**	(c)	**18.**	(b)
19.	(a)	**20.**	(b)	**21.**	(c)	**22.**	(a)	**23.**	(b)	**24.**	(a)	**25.**	(b)	**26.**	(c)	**27.**	(c)
28.	(b)	**29.**	(b)	**30.**	(c)	**31.**	(b)	**32.**	(b)	**33.**	(d)	**34.**	(d)	**35.**	(b)	**36.**	(d)
37.	(d)	**38.**	(a)	**39.**	(b)	**40.**	(d)	**41.**	(b)	**42.**	(b)	**43.**	(c)	**44.**	(b)	**45.**	(a)

Unit Test 3

1.	(c)	**2.**	(c)	**3.**	(c)	**4.**	(d)	**5.**	(d)	**6.**	(d)	**7.**	(c)	**8.**	(a)	**9.**	(c)
10.	(a)	**11.**	(d)	**12.**	(c)	**13.**	(a)	**14.**	(a)	**15.**	(c)	**16.**	(b)	**17.**	(d)	**18.**	(c)
19.	(a)	**20.**	(d)	**21.**	(b)	**22.**	(b)	**23.**	(c)	**24.**	(b)	**25.**	(c)	**26.**	(a)	**27.**	(c)
28.	(b)	**29.**	(b)	**30.**	(a)	**31.**	(c)	**32.**	(d)	**33.**	(b)	**34.**	(c)	**35.**	(d)	**36.**	(d)
37.	(a)	**38.**	(b)	**39.**	(b)	**40.**	(b)	**41.**	(d)	**42.**	(a)	**43.**	(a)	**44.**	(a)	**45.**	(a)

Unit Test 4

1.	(d)	**2.**	(b)	**3.**	(a)	**4.**	(d)	**5.**	(a)	**6.**	(b)	**7.**	(a)	**8.**	(b)	**9.**	(b)
10.	(d)	**11.**	(a)	**12.**	(c)	**13.**	(c)	**14.**	(d)	**15.**	(a)	**16.**	(c)	**17.**	(a)	**18.**	(b)
19.	(d)	**20.**	(c)	**21.**	(c)	**22.**	(b)	**23.**	(a)	**24.**	(a)	**25.**	(d)	**26.**	(c)	**27.**	(c)
28.	(d)	**29.**	(a)	**30.**	(d)	**31.**	(d)	**32.**	(a)	**33.**	(a)	**34.**	(b)	**35.**	(b)	**36.**	(c)
37.	(b)	**38.**	(c)	**39.**	(b)	**40.**	(d)	**41.**	(c)	**42.**	(b)	**43.**	(b)	**44.**	(c)	**45.**	(a)

Unit Test 5

1.	(d)	**2.**	(c)	**3.**	(a)	**4.**	(b)	**5.**	(a)	**6.**	(c)	**7.**	(d)	**8.**	(c)	**9.**	(b)
10.	(d)	**11.**	(a)	**12.**	(c)	**13.**	(d)	**14.**	(d)	**15.**	(a)	**16.**	(c)	**17.**	(d)	**18.**	(b)
19.	(c)	**20.**	(c)	**21.**	(c)	**22.**	(c)	**23.**	(a)	**24.**	(d)	**25.**	(b)	**26.**	(a)	**27.**	(c)
28.	(a)	**29.**	(c)	**30.**	(d)	**31.**	(c)	**32.**	(d)	**33.**	(c)	**34.**	(d)	**35.**	(d)	**36.**	(a)
37.	(d)	**38.**	(a)	**39.**	(a)	**40.**	(a)	**41.**	(d)	**42.**	(c)	**43.**	(d)	**44.**	(c)	**45.**	(b)

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NEET 2017

SOLVED PAPER

1. A spring of force constant k is cut into lengths of ratio 1 : 2 : 3. They are connected in series and the new force constant is k'. Then they are connected in parallel and force constant is k''. Then $k' : k''$ is

(a) 1 : 9 (b) 1 : 11 (c) 1 : 14 (d) 1 : 6

2. The ratio of resolving powers of an optical microscope for two wavelengths $\lambda_1 = 4000$ Å and $\lambda_2 = 6000$ Å is

(a) 9 : 4 (b) 3 : 2 (c) 16 : 81 (d) 8 : 27

3. The two nearest harmonics of a tube closed at one end and open at other end are 220 Hz and 260 Hz. What is the fundamental frequency of the system?

(a) 20 Hz (b) 30 Hz (c) 40 Hz (d) 10 Hz

4. Consider a drop of rain water having mass 1 g falling from a height of 1 km. It hits the ground with a speed of 50 $m s^{-1}$. Take 'g' constant with a value 10 $m\ s^{-2}$. The work done by the (i) gravitational force and the (ii) resistive force of air is

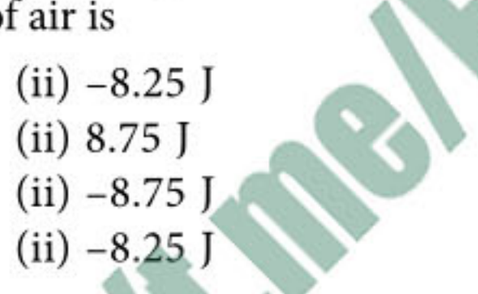
(a) (i) 1.25 J (ii) −8.25 J
(b) (i) 100 J (ii) 8.75 J
(c) (i) 10 J (ii) −8.75 J
(d) (i) −10 J (ii) −8.25 J

5. A physical quantity of the dimensions of length that can be formed out of c, G and $\frac{e^2}{4\pi\varepsilon_0}$ is [c is velocity of light, G is universal constant of gravitation and e is charge]

(a) $c^2\left[G\frac{e^2}{4\pi\varepsilon_0}\right]^{1/2}$ (b) $\frac{1}{c^2}\left[\frac{e^2}{G\,4\pi\varepsilon_0}\right]^{1/2}$

(c) $\frac{1}{c}G\frac{e^2}{4\pi\varepsilon_0}$ (d) $\frac{1}{c^2}\left[G\frac{e^2}{4\pi\varepsilon_0}\right]^{1/2}$

6. Two rods A and B of different materials are welded together as shown in figure. Their thermal conductivities are K_1 and K_2.



The thermal conductivity of the composite rod will be

(a) $\frac{3(K_1+K_2)}{2}$ (b) $K_1 + K_2$

(c) $2(K_1 + K_2)$ (d) $\frac{K_1+K_2}{2}$

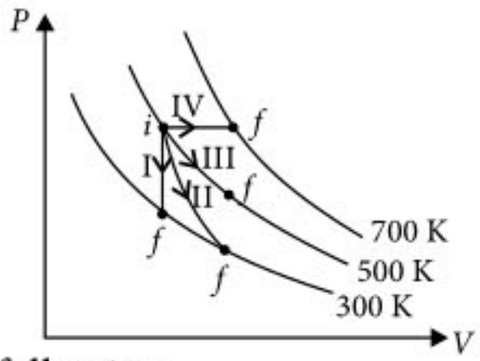
7. A capacitor is charged by a battery. The battery is removed and another identical uncharged capacitor is connected in parallel. The total electrostatic energy of resulting system

(a) decreases by a factor of 2
(b) remains the same
(c) increases by a factor of 2
(d) increases by a factor of 4

8. In a common emitter transistor amplifier the audio signal voltage across the collector is 3 V. The resistance of collector is 3 kΩ. If current gain is 100 and the base resistance is 2 kΩ, the voltage and power gain of the amplifier is

(a) 15 and 200 (b) 150 and 15000
(c) 20 and 2000 (d) 200 and 1000

9. Thermodynamic processes are indicated in the following diagram.



Match the following

	Column-1		Column-2
P.	Process I	A.	Adiabatic
Q.	Process II	B.	Isobaric
R.	Process III	C.	Isochoric
S.	Process IV	D.	Isothermal

(a) P→C, Q→A, R→D, S→B
(b) P→C, Q→D, R→B, S→A
(c) P→D, Q→B, R→A, S→C
(d) P→A, Q→C, R→D, S→B

10. Suppose the charge of a proton and an electron differ slightly. One of them is $-e$, the other is $(e+\Delta e)$. If the net of electrostatic force and gravitational force between two hydrogen atoms placed at a distance d (much greater than atomic size) apart is zero, then Δe is of the order of [Given mass of hydrogen $[m_h = 1.67 \times 10^{-27}$ kg]

(a) 10^{-23} C (b) 10^{-37} C
(c) 10^{-47} C (d) 10^{-20} C

11. The resistance of a wire is 'R' ohm. If it is melted and stretched to 'n' times its original length, its new resistance will be

(a) $\frac{R}{n}$ (b) n^2R (c) $\frac{R}{n^2}$ (d) nR

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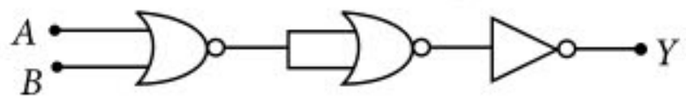
12. The given electrical network is equivalent to

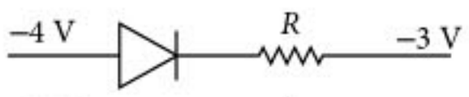


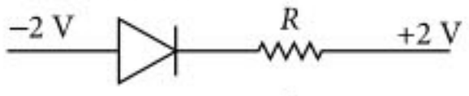
(a) OR gate (b) NOR gate
(c) NOT gate (d) AND gate

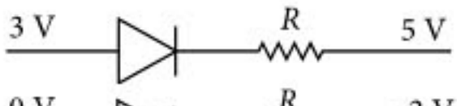
13. The de-Broglie wavelength of a neutron in thermal equilibrium with heavy water at a temperature T (kelvin) and mass m, is

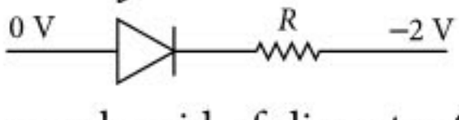
(a) $\frac{h}{\sqrt{3mkT}}$ (b) $\frac{2h}{\sqrt{3mkT}}$
(c) $\frac{2h}{\sqrt{mkT}}$ (d) $\frac{h}{\sqrt{mkT}}$

14. Which one of the following represents forward bias diode?

(a) 

(b) 

(c) 

(d) 

15. A long solenoid of diameter 0.1 m has 2×10^4 turns per meter. At the centre of the solenoid, a coil of 100 turns and radius 0.01 m is placed with its axis coinciding with the solenoid axis. The current in the solenoid reduces at a constant rate to 0 A from 4 A in 0.05 s. If the resistance of the coil is $10\pi^2\ \Omega$, the total charge flowing through the coil during this time is

(a) 16 μC (b) 32 μC
(c) 16 π μC (d) 32 π μC

16. Preeti reached the metro station and found that the escalator was not working. She walked up the stationary escalator in time t_1. On other days, if she remains stationary on the moving escalator, then the escalator takes her up in time t_2. The time taken by her to walk up on the moving escalator will be

(a) $\frac{t_1 t_2}{t_2 - t_1}$ (b) $\frac{t_1 t_2}{t_2 + t_1}$ (c) $t_1 - t_2$ (d) $\frac{t_1 + t_2}{2}$

17. Young's double slit experiment is first performed in air and then in a medium other than air. It is found that 8^{th} bright fringe in the medium lies where 5^{th} dark fringe lies in air. The refractive index of the medium is nearly

(a) 1.59 (b) 1.69 (c) 1.78 (d) 1.25

18. A beam of light from a source L is incident normally on a plane mirror fixed at a certain distance x from the source. The beam is reflected back as a spot on a scale placed just above the source L. When themirror is rotated through a small angle θ, the spot of the light is found to move through a distance y on the scale. The angle θ is given by

(a) $\frac{y}{x}$ (b) $\frac{x}{2y}$ (c) $\frac{x}{y}$ (d) $\frac{y}{2x}$

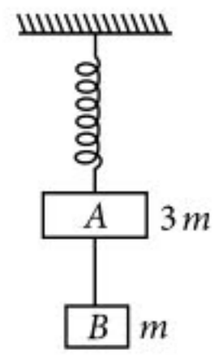
19. If θ_1 and θ_2 be the apparent angles of dip observed in two vertical planes at right angles to each other, then the true angle of dip θ is given by

(a) $\tan^2\theta = \tan^2\theta_1 + \tan^2\theta_2$
(b) $\cot^2\theta = \cot^2\theta_1 - \cot^2\theta_2$
(c) $\tan^2\theta = \tan^2\theta_1 - \tan^2\theta_2$
(d) $\cot^2\theta = \cot^2\theta_1 + \cot^2\theta_2$

20. Two cars moving in opposite directions approach each other with speed of 22 m s^{-1} and 16.5 m s^{-1} respectively. The driver of the first car blows a horn having a frequency 400 Hz. The frequency heard by the driver of the second car is [velocity of sound 340 m s^{-1}]

(a) 361 Hz (b) 411 Hz
(c) 448 Hz (d) 350 Hz

21. Two blocks A and B of masses $3m$ and m respectively are connected by a massless and inextensible string. The whole system is suspended by a massless spring as shown in figure. The magnitudes of acceleration of A and B immediately after the string is cut, are respectively



(a) $\frac{g}{3}, g$ (b) g, g (c) $\frac{g}{3}, \frac{g}{3}$ (d) $g, \frac{g}{3}$

22. A thin prism having refracting angle 10° is made of glass of refractive index 1.42. This prism is combined with another thin prism of glass of refractive index 1.7. This combination produces dispersion without deviation. The refracting angle of second prism should be

(a) 6° (b) 8° (c) 10° (d) 4°

23. The acceleration due to gravity at a height 1 km above the earth is the same as at a depth d below the surface of earth. Then

(a) $d = 1$ km (b) $d = \frac{3}{2}$ km
(c) $d = 2$ km (d) $d = \frac{1}{2}$ km

24. A potentiometer is an accurate and versatile device to make electrical measurements of EMF because the method involves

(a) potential gradients
(b) a condition of no current flow through the galvanometer
(c) a combination of cells, galvanometer and resistances
(d) cells

25. A spherical black body with a radius of 12 cm radiates 450 watt power at 500 K. If the radius were halved and the temperature doubled, the power radiated in watt would be

(a) 450 (b) 1000 (c) 1800 (d) 225

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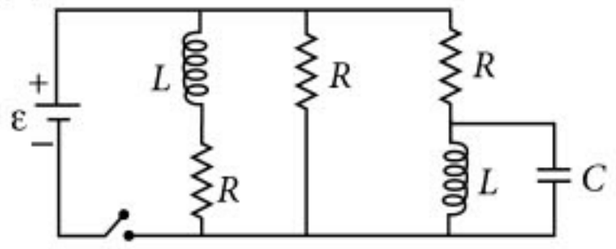
26. Figure shows a circuit that contains three identical resistors with resistance $R = 9.0\ \Omega$ each, two identical inductors with inductance $L = 2.0$ mH each, and an ideal battery with emf $\varepsilon = 18$ V. The current i through the battery just after the switch closed is

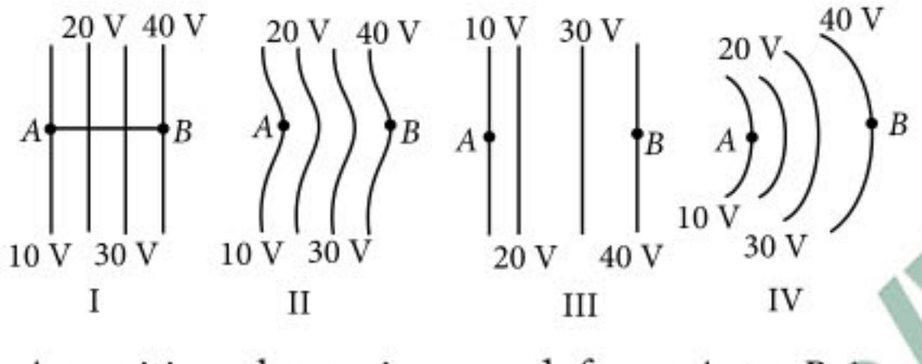


(a) 0.2 A (b) 2 A (c) 0 ampere (d) 2 mA

27. Radioactive material 'A' has decay constant '8λ' and material 'B' has decay constant 'λ'. Initially they have same number of nuclei. After what time, the ratio of number of nuclei of material 'B' to that 'A' will be $\frac{1}{e}$?

(a) $\frac{1}{7\lambda}$ (b) $\frac{1}{8\lambda}$ (c) $\frac{1}{9\lambda}$ (d) $\frac{1}{\lambda}$

28. The diagrams below show regions of equipotentials.



A positive charge is moved from A to B in each diagram.

(a) In all the four cases the work done is the same.
(b) Minimum work is required to move q in figure (I).
(c) Maximum work is required to move q in figure (II).
(d) Maximum work is required to move q in figure (III).

29. Two astronauts are floating in gravitational free space after having lost contact with their spaceship. The two will

(a) move towards each other.
(b) move away from each other.
(c) will become stationary.
(d) keep floating at the same distance between them.

30. The x and y coordinates of the particle at any time are $x = 5t - 2t^2$ and $y = 10t$ respectively, where x and y are in metres and t in seconds. The acceleration of the particle at $t = 2$ s is

(a) 5 m s^{-2} (b) −4 m s^{-2}
(c) −8 m s^{-2} (d) 0

31. One end of string of length l is connected to a particle of mass 'm' and the other end is connected to a small peg on a smooth horizontal table. If the particle moves in circle with speed 'v', the net force on the particle (directed towards centre) will be (T represents the tension in the string)

(a) $T + \frac{mv^2}{l}$ (b) $T - \frac{mv^2}{l}$
(c) zero (d) T

32. A particle executes linear simple harmonic motion with an amplitude of 3 cm. When the particle is at 2 cm from the mean position, the magnitude of its velocity is equal to that of its acceleration. Then its time period in seconds is

(a) $\frac{\sqrt{5}}{2\pi}$ (b) $\frac{4\pi}{\sqrt{5}}$ (c) $\frac{2\pi}{\sqrt{3}}$ (d) $\frac{\sqrt{5}}{\pi}$

33. Two polaroids P_1 and P_2 are placed with their axis perpendicular to each other. Unpolarised light I_0 is incident on P_1. A third polaroid P_3 is kept in between P_1 and P_2 such that its axis makes an angle 45° with that of P_1. The intensity of transmitted light through P_2 is

(a) $\frac{I_0}{4}$ (b) $\frac{I_0}{8}$ (c) $\frac{I_0}{16}$ (d) $\frac{I_0}{2}$

34. The bulk modulus of a spherical object is 'B'. If it is subjected to uniform pressure 'p', the fractional decrease in radius is

(a) $\frac{B}{3p}$ (b) $\frac{3p}{B}$ (c) $\frac{p}{3B}$ (d) $\frac{p}{B}$

35. In an electromagnetic wave in free space the root mean square value of the electric field is $E_{rms} = 6$ V m^{-1}. The peak value of the magnetic field is

(a) 2.83×10^{-8} T (b) 0.70×10^{-8} T
(c) 4.23×10^{-8} T (d) 1.41×10^{-8} T

36. A rope is wound around a hollow cylinder of mass 3 kg and radius 40 cm. What is the angular acceleration of the cylinder if the rope is pulled with a force of 30 N?

(a) 0.25 rad s^{-2} (b) 25 rad s^{-2}
(c) 5 m s^{-2} (d) 25 m s^{-2}

37. Two discs of same moment of inertia rotating about their regular axis passing through centre and perpendicular to the plane of disc with angular velocities ω_1 and ω_2. They are brought into contact face to face coinciding the axis of rotation. The expression for loss of energy during this process is

(a) $\frac{1}{4}I(\omega_1 - \omega_2)^2$ (b) $I(\omega_1 - \omega_2)^2$
(c) $\frac{1}{8}I(\omega_1 - \omega_2)^2$ (d) $\frac{1}{2}I(\omega_1 + \omega_2)^2$

38. The photoelectric threshold wavelength of silver is 3250×10^{-10} m. The velocity of the electron ejected from a silver surface by ultraviolet light of wavelength 2536×10^{-10} m is

[Given $h = 4.14 \times 10^{-15}$ eV s and $c = 3 \times 10^8$ m s^{-1}]

(a) $\approx 0.6 \times 10^6$ m s^{-1} (b) $\approx 61 \times 10^3$ m s^{-1}
(c) $\approx 0.3 \times 10^6$ m s^{-1} (d) $\approx 6 \times 10^5$ m s^{-1}

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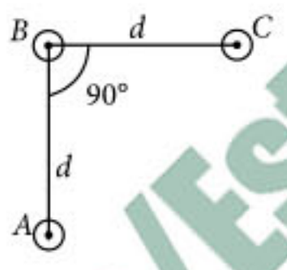
39. A 250-turn rectangular coil of length 2.1 cm and width 1.25 cm carries a current of 85 μA and subjected to a magnetic field of strength 0.85 T. Work done for rotating the coil by 180° against the torque is
(a) 4.55 μJ (b) 2.3 μJ (c) 1.15 μJ (d) 9.1 μJ

40. The ratio of wavelengths of the last line of Balmer series and the last line of Lyman series is
(a) 1 (b) 4 (c) 0.5 (d) 2

41. A carnot engine having an efficiency of $\frac{1}{10}$ as heat engine, is used as a refrigerator. If the work done on the system is 10 J, the amount of energy absorbed from the reservoir at lower temperature is
(a) 90 J (b) 99 J (c) 100 J (d) 1 J

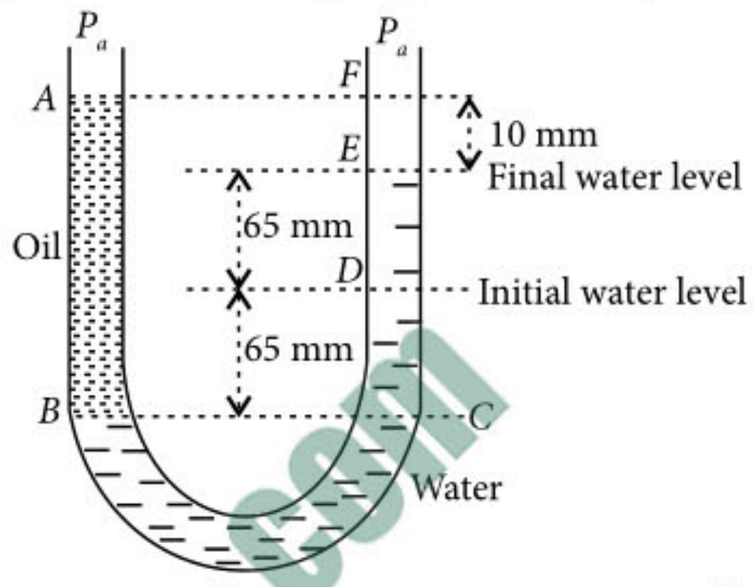
42. A gas mixture consists of 2 moles of O_2 and 4 moles of Ar at temperature T. Neglecting all vibrational modes, the total internal energy of the system is
(a) 15 RT (b) 9 RT (c) 11 RT (d) 4 RT

43. An arrangement of three parallel straight wires placed perpendicular to plane of paper carrying same current 'I' along the same direction as shown in figure. Magnitude of force per unit length on the middle wire 'B' is given by



(a) $\frac{2\mu_0 I^2}{\pi d}$ (b) $\frac{\sqrt{2}\mu_0 I^2}{\pi d}$ (c) $\frac{\mu_0 I^2}{\sqrt{2}\pi d}$ (d) $\frac{\mu_0 I^2}{2\pi d}$

44. A U tube with both ends open to the atmosphere, is partially filled with water. Oil, which is immiscible with water, is poured into one side until it stands at a distance of 10 mm above the water level on the other side. Meanwhile the water rises by 65 mm from its original level (see diagram). The density of the oil is



(a) 425 kg m^{-3} (b) 800 kg m^{-3}
(c) 928 kg m^{-3} (d) 650 kg m^{-3}

45. Which of the following statements are correct?
(1) Centre of mass of a body always coincides with the centre of gravity of the body.
(2) Centre of mass of a body is the point at which the total gravitational torque on the body is zero.
(3) A couple on a body produces both translational and rotational motion in a body.
(4) Mechanical advantage greater than one means that small effort can be used to lift a large load.
(a) (1) and (2) (b) (2) and (3)
(c) (3) and (4) (d) (2) and (4)

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1. (b) : Let us assume, the length of spring be l.
When we cut the spring into ratio of length 1 : 2 : 3, we get three springs of lengths $\frac{l}{6}, \frac{2l}{6}$ and $\frac{3l}{6}$ with force constant,

$$\therefore \quad k_1 = \frac{kl}{l_1} = \frac{kl}{l/6} = 6k \; ; \; k_2 = \frac{kl}{l_2} = \frac{kl}{2l/6} = 3k$$

$$k_3 = \frac{kl}{l_3} = \frac{kl}{3l/6} = 2k$$

When connected in series,

$$\frac{1}{k'} = \frac{1}{6k} + \frac{1}{3k} + \frac{1}{2k} = \frac{1+2+3}{6k} = \frac{1}{k}$$

$$\therefore \quad k' = k$$

When connected in parallel,

$$k'' = 6k + 3k + 2k = 11k$$

$$\frac{k'}{k''} = \frac{k}{11k} = \frac{1}{11}$$

2. (b) : The resolving power of an optical microscope,

$$\text{RP} = \frac{2\mu \sin\theta}{\lambda}$$

$$\therefore \quad \frac{\text{RP}_1}{\text{RP}_2} = \frac{6000}{4000} = \frac{3}{2}$$

3. (a) : Nearest harmonics of an organ pipe closed at one end is differ by twice of its fundamental frequency.
$\therefore$ 260 – 220 = 2υ, $\quad \upsilon = 20$ Hz

4. (c) : Here, $m = 1$ g $= 10^{-3}$ kg, $h = 1$ km $= 1000$ m, $v = 50$ m s^{-1}, $g = 10$ m s^{-2}.
(i) The work done by the gravitational force
$= mgh = 10^{-3} \times 10 \times 1000 = 10$ J
(ii) The total work done by gravitational force and the resistive force of air is equal to change in kinetic energy of rain drop.

$$\therefore \quad W_g + W_r = \frac{1}{2}mv^2 - 0$$

$$10 + W_r = \frac{1}{2} \times 10^{-3} \times 50 \times 50 \quad \text{or} \quad W_r = -8.75 \text{ J}$$

5. (d) : Dimensions of

$$\frac{e^2}{4\pi\varepsilon_o} = [F \times d^2] = [\text{ML}^3\text{T}^{-2}]$$

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Dimensions of $G = [M^{-1}L^3T^{-2}]$,
Dimensions of $c = [LT^{-1}]$

$$l \propto \left(\frac{e^2}{4\pi\varepsilon_o}\right)^p G^q c^r$$

$\therefore \quad [L^1] = [ML^3T^{-2}]^p\,[M^{-1}L^3T^{-2}]^q\,[LT^{-1}]^r$

On comparing both sides and solving, we get

$$p = \frac{1}{2}, \quad q = \frac{1}{2} \text{ and } r = -2$$

$$\therefore \quad l = \frac{1}{c^2}\left[\frac{Ge^2}{4\pi\varepsilon_o}\right]^{1/2}$$

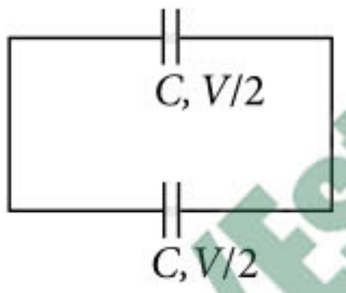
6. (d) : Equivalent thermal conductivity of the composite rod in parallel combination will be,

$$K = \frac{K_1A_1 + K_2A_2}{A_1 + A_2} = \frac{K_1 + K_2}{2}$$

7. (a) : When the capacitor is charged by a battery of potential V, then energy stored in the capacitor,

$$U_i = \frac{1}{2}CV^2 \qquad ...(i)$$

When the battery is removed and another identical uncharged capacitor is connected in parallel



Common potential,

$$V' = \frac{CV}{C+C} = \frac{V}{2}$$

$\therefore$ Then the energy stored in the capacitor,

$$U_f = \frac{1}{2}(2C)\left(\frac{V}{2}\right)^2 = \frac{1}{4}CV^2 \qquad ...(ii)$$

$\therefore$ From eqns. (i) and (ii); $U_f = \frac{U_i}{2}$ that means the total electrostatic energy of resulting system will decrease by a factor of 2.

8. (b) : Given: $V_i = 3\,V$, $R_C = 3\,k\Omega$, $R_B = 2\,k\Omega$, $\beta = 100$

Voltage gain of the CE amplifier,

$$A_V = -\beta_{ac}\left(\frac{R_C}{R_B}\right) = -100\left(\frac{3}{2}\right) = -150$$

Power gain, $A_P = \beta \times A_V = 100 \times (-150) = -15000$

Negative sign represents that output voltage is in opposite phase with the input voltage.

9. (a) : In process I, volume is constant

$\therefore$ Process I $\rightarrow$ Isochoric; P $\rightarrow$ C

As slope of curve II is more than the slope of curve III.

Process II $\rightarrow$ Adiabatic and Process III $\rightarrow$ Isothermal

$\therefore \quad$ Q $\rightarrow$ A, R $\rightarrow$ D

In process IV, pressure is constant

Process IV $\rightarrow$ Isobaric; S $\rightarrow$ B

10. (b) : A hydrogen atom consists of an electron and a proton.

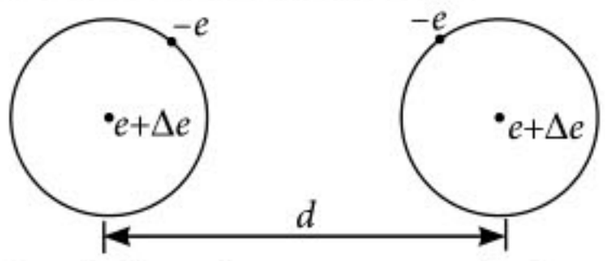
$\therefore$ Charge on one hydrogen atom

$$= q_e + q_p = -e + (e + \Delta e) = \Delta e$$

Since a hydrogen atom carry a net charge Δe,

$\therefore$ Electrostatic force, $F_e = \frac{1}{4\pi\varepsilon_o}\frac{(\Delta e)^2}{d^2}$ ...(i)

will act between two hydrogen atoms.



The gravitational force between two hydrogen atoms is given as

$$F_g = \frac{Gm_hm_h}{d^2} \qquad ...(ii)$$

Since, the net force on the system is zero, $F_e = F_g$

Using eqns. (i) and (ii), we get

$$\frac{(\Delta e)^2}{4\pi\varepsilon_o d^2} = \frac{Gm_h^2}{d^2}$$

$$(\Delta e)^2 = 4\pi\varepsilon_o Gm_h^2 = 6.67 \times 10^{-11} \times (1.67 \times 10^{-27})^2/(9 \times 10^9)$$

$$\Delta e \approx 10^{-37}\,C$$

11. (b) : The resistance of a wire of length l and area A and resistivity ρ is given as

$$R = \frac{\rho l}{A}$$

Given, $l' = nl$

As the volume of the wire remains constant

$\therefore \quad A'l' = Al$

$$A' = \frac{Al}{l'} = \frac{Al}{nl} \quad \text{or} \quad A' = \frac{A}{n}$$

$$\therefore \quad R' = \frac{\rho l'}{A'} = \frac{\rho nl}{\frac{A}{n}} = \frac{n^2\rho l}{A} = n^2R$$

12. (b)

13. (a) : Kinetic energy of a neutron in thermal equilibrium with heavy water at a temperature T is given as

$$K = \frac{3}{2}kT \qquad ...(i)$$

Also momentum (p) is, $p = \sqrt{2mK}$

From eqn. (i)

$$p = \sqrt{2m \cdot \frac{3}{2}kT} = \sqrt{3mkT}$$

Required de-Broglie wavelength is given as

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{3mkT}}$$

14. (d) : A diode is said to be forward biased if p-side is at higher potential than n-side of p-n junction.

15. (b) : Given $n = 2 \times 10^4$; $I = 4\,A$

Initially $I = 0$ A

$\therefore \quad B_i = 0$ or $\phi_i = 0$

Finally, the magnetic field at the centre of the solenoid is given as

$B_f = \mu_o nI$

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$B_f = 4\pi \times 10^{-7} \times 2 \times 10^4 \times 4$

$B_f = 32\pi \times 10^{-3}$ T

Final magnetic flux through the coil is given as

$\phi_f = nBA$

$= 100 \times 32\,\pi \times 10^{-3} \times \pi \times (0.01)^2$

$\phi_f = 32\pi^2 \times 10^{-5}$ T m^2

Induced charge,

$$q = \frac{|\Delta\phi|}{R} = \frac{|\phi_f - \phi_i|}{R} = \frac{32\pi^2 \times 10^{-5}}{10\pi^2} = 32 \times 10^{-6}\ \text{C} = 32\ \mu\text{C}$$

16. (b) : Let v_1 is the velocity of Preeti on stationary escalator and d is the distance travelled by her

$$\therefore \quad v_1 = \frac{d}{t_1}$$

Again, let v_2 is the velocity of escalator

$$\therefore \quad v_2 = \frac{d}{t_2}$$

$\therefore$ Net velocity of Preeti on moving escalator with respect to the ground

$$v = v_1 + v_2 = \frac{d}{t_1} + \frac{d}{t_2} = d\left(\frac{t_1 + t_2}{t_1 t_2}\right)$$

The time taken by her to walk up on the moving escalator will be

$$t = \frac{d}{v} = \frac{d}{d\left(\frac{t_1 + t_2}{t_1 t_2}\right)} = \frac{t_1 t_2}{t_1 + t_2}$$

17. (c) : Position of 8th bright fringe in medium,

$$x = \frac{8\lambda_m D}{d}$$

Position of 5th dark fringe in air,

$$x' = \frac{\left(5 - \frac{1}{2}\right)\lambda_{air} D}{d} = \frac{4.5\,\lambda_{air} D}{d}$$

Given $x = x'$

$$\therefore \quad \frac{8\lambda_m D}{d} = \frac{4.5\lambda_{air} D}{d}$$

$$\mu_m = \frac{\lambda_{air}}{\lambda_m} = \frac{8}{4.5} \simeq 1.78$$

18. (d) : When mirror is rotated by θ angle reflected ray will be rotated by 2θ.

For small angle θ,

$$\tan 2\theta \approx 2\theta = \frac{y}{x}$$

$$\therefore \quad \theta = \frac{y}{2x}$$

19. (d)

20. (c) : The required frequency of sound heard by the driver of second car is given as

$$\upsilon' = \upsilon\left(\frac{v + v_o}{v - v_s}\right)$$

$$\upsilon' = 400\left(\frac{340 + 16.5}{340 - 22}\right) = 400\left(\frac{356.5}{318}\right)$$

$$\upsilon' \approx 448\ \text{Hz}$$

21. (a) : Before the string is cut

$kx = T + 3mg$ ...(i)

$T = mg$ ...(ii)

From eqns. (i) and (ii)

$kx = 4mg$

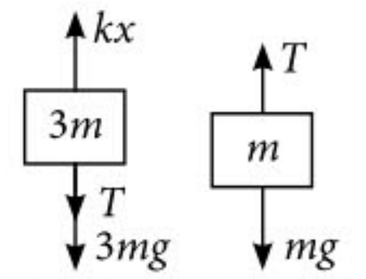
Just after the string is cut $T = 0$

$$a_A = \frac{kx - 3mg}{3m}$$

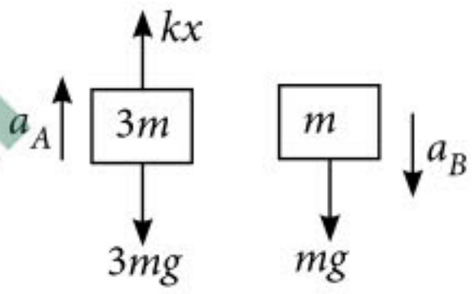
$$a_A = \frac{4mg - 3mg}{3m}$$

$$= \frac{mg}{3m} = \frac{g}{3}$$

and also $a_B = g$



Before the string is cut



After the string is cut

22. (a) : The condition for dispersion without deviation is given as $(\mu - 1)A = (\mu' - 1)A'$

Given $\mu = 1.42$, $A = 10°$, $\mu' = 1.7$, $A' = ?$

$$\therefore \quad (1.42 - 1) \times 10 = (1.7 - 1)A' \text{ or, } A' = \frac{0.42 \times 10}{0.7} = 6°$$

23. (c) : Given, $g_h = g_d \Rightarrow g\left(1 - \frac{2h}{R_e}\right) = g\left(1 - \frac{d}{R_e}\right)$

$$\therefore \quad d = 2h = 2 \times 1 = 2\ \text{km} \qquad (\because\ h = 1\ \text{km})$$

24. (b)

25. (c) : According to Stefan-Boltzman law, rate of energy radiated by a black body is given as

$E = \sigma A T^4 = \sigma 4\pi R^2 T^4$

Given $E_1 = 450$ W, $T_1 = 500$ K, $R_1 = 12$ cm

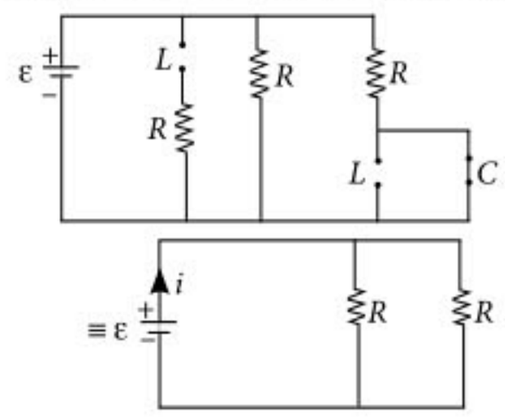
$R_2 = \frac{R_1}{2}$, $T_2 = 2T_1$, $E_2 = ?$

$$\frac{E_2}{E_1} = \frac{\sigma 4\pi R_2^2 T_2^4}{\sigma 4\pi R_1^2 T_1^4} = \left(\frac{R_2}{R_1}\right)^2 \left(\frac{T_2}{T_1}\right)^4 = \frac{1}{4} \times 16 = 4$$

$E_2 = E_1 \times 4 = 450 \times 4 = 1800$ W

26. (*) : At time, $t = 0$ *i.e.*, when switch is closed, inductor in the circuit provides very high resistance (open circuit) while capacitor starts charging with maximum current (low resistance).

Equivalent circuit of the given circuit



Current drawn from battery,

$$i = \frac{\varepsilon}{(R/2)} = \frac{2\varepsilon}{R} = \frac{2 \times 18}{9} = 4\ \text{A}$$

*None of the given options is correct.

27. (*) : The number of radioactive nuclei 'N' at any time t is given as

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$N(t) = N_0 e^{-\lambda t}$

where N_0 is number of radioactive nuclei in the sample at some aribitrary time $t = 0$ and λ is the radioactive decay constant.

Given: $\lambda_A = 8\lambda,\ \lambda_B = \lambda,\ N_{0A} = N_{0B} = N_0$

$$\therefore \quad \frac{N_B}{N_A} = \frac{e^{-\lambda t}}{e^{-8\lambda t}}$$

$$\frac{1}{e} = e^{-\lambda t} e^{8\lambda t} = e^{7\lambda t} \implies -1 = 7\lambda t \text{ or } t = \frac{-1}{7\lambda}$$

*Question is not properly framed.

28. (a) : Work done is given as $W = q\Delta V$

In all the four cases the potential difference from A to B is same.

∴ In all the four cases the work done is same.

29. (a) : Since two astronauts are floating in gravitational free space. The only force acting on the two astronauts is the gravitational pull of their masses,

$$F = \frac{Gm_1m_2}{r^2},$$

which is attractive in nature.

Hence they move towards each other.

30. (b): $x = 5t - 2t^2, \quad y = 10t$

$$\frac{dx}{dt} = 5 - 4t, \quad \frac{dy}{dt} = 10 \qquad \therefore \quad v_x = 5 - 4t, \quad v_y = 10$$

$$\frac{dv_x}{dt} = -4, \quad \frac{dv_y}{dt} = 0 \ \therefore \quad a_x = -4, \quad a_y = 0$$

Acceleration, $\vec{a} = a_x\hat{i} + a_y\hat{j} = -4\hat{i}$

∴ The acceleration of the particle at $t = 2$ s is $-4\ \text{m s}^{-2}$.

31. (d) : Centripetal force $\left(\frac{mv^2}{l}\right)$ is provided by tension so net force on the particle will be equal to tension T.

32. (b) : Given, $A = 3$ cm, $x = 2$ cm

The velocity of a particle in simple harmonic motion is given as

$$v = \omega\sqrt{A^2 - x^2}$$

and magnitude of its acceleration is $a = \omega^2 x$

Given $|v| = |a|$

$$\therefore \quad \omega\sqrt{A^2 - x^2} = \omega^2 x$$

$$\omega x = \sqrt{A^2 - x^2} \quad \text{or} \quad \omega^2 x^2 = A^2 - x^2$$

$$\omega^2 = \frac{A^2 - x^2}{x^2} = \frac{9-4}{4} = \frac{5}{4}$$

$$\omega = \frac{\sqrt{5}}{2}$$

Time period, $T = \frac{2\pi}{\omega} = 2\pi \cdot \frac{2}{\sqrt{5}} = \frac{4\pi}{\sqrt{5}}$ s

33. (b) : The intensity of transmitted light through P_1,

$$I_1 = \frac{I_o}{2}$$

The intensity of transmitted light through P_3,

$$I_2 = I_1 \cos^2 45°$$

$$= \frac{I_o}{2}\left(\frac{1}{\sqrt{2}}\right)^2 = \frac{I_o}{2} \cdot \frac{1}{2} = \frac{I_o}{4}$$

Angle between polaroids P_3 and $P_2 = (90° - 45°) = 45°$

∴ Intensity of transmitted light through P_2,

$$I_3 = I_2 \cos^2 45° = \frac{I_o}{4}\left(\frac{1}{\sqrt{2}}\right)^2 = \frac{I_o}{8}$$

34. (c) : Bulk modulus B is given as

$$B = \frac{-pV}{\Delta V} \qquad ...(i)$$

The volume of a spherical object of radius r is given as

$$V = \frac{4}{3}\pi r^3, \quad \Delta V = \frac{4}{3}\pi(3r^2)\Delta r \quad \therefore \quad \frac{V}{\Delta V} = \frac{r}{3\Delta r}$$

Put this value in eqn. (i), we get $B = -\frac{pr}{3\Delta r}$

Fractional decrease in radius is, $-\frac{\Delta r}{r} = \frac{p}{3B}$

35. (a)

36. (b) : $m = 3$ kg, $r = 40$ cm $= 40 \times 10^{-2}$ m, $F = 30$ N

Moment of inertia of hollow cylinder about its axis

$$= mr^2 = 3\ \text{kg} \times (0.4)^2\ \text{m}^2 = 0.48\ \text{kg m}^2$$

The torque is given by,

$$\tau = I\alpha$$

where I = moment of inertia,

α = angular acceleration

In the given case, $\tau = rF$, as the force is acting perpendicularly to the radial vector.

$$\therefore \quad \alpha = \frac{\tau}{I} = \frac{Fr}{mr^2} = \frac{F}{mr} = \frac{30}{3 \times 40 \times 10^{-2}} = \frac{30 \times 100}{3 \times 40}$$

$$\alpha = 25\ \text{rad s}^{-2}$$

37. (a) : Initial angular momentum $= I\omega_1 + I\omega_2$

Let ω be angular speed of the combined system.

Final angular momentum $= 2I\omega$

∴ According to conservation of angular momentum

$$I\omega_1 + I\omega_2 = 2I\omega \quad \text{or} \quad \omega = \frac{\omega_1 + \omega_2}{2}$$

Initial rotational kinetic energy

$$E_i = \frac{1}{2}I(\omega_1^2 + \omega_2^2)$$

Final rotational kinetic energy

$$E_f = \frac{1}{2}(2I)\omega^2$$

$$= \frac{1}{2}(2I)\left(\frac{\omega_1 + \omega_2}{2}\right)^2 = \frac{1}{4}I(\omega_1 + \omega_2)^2$$

$$\therefore \quad \text{Loss of energy, } \Delta E = E_i - E_f$$

$$= \frac{I}{2}(\omega_1^2 + \omega_2^2) - \frac{I}{4}(\omega_1^2 + \omega_2^2 + 2\omega_1\omega_2)$$

$$= \frac{I}{4}\left[\omega_1^2 + \omega_2^2 - 2\omega_1\omega_2\right] = \frac{I}{4}(\omega_1 - \omega_2)^2$$

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38. (a,d) : The maximum kinetic energy is given as

$$K_{max} = h\upsilon - \phi_0 = h\upsilon - h\upsilon_o = \frac{hc}{\lambda} - \frac{hc}{\lambda_0}$$

where λ_0 = threshold wavelength

or $\frac{1}{2}mv^2 = \frac{hc}{\lambda} - \frac{hc}{\lambda_0}$

Here, $h = 4.14 \times 10^{-15}$ eV s, $c = 3 \times 10^8$ m s^{-1}

$\lambda_o = 3250 \times 10^{-10}$ m $= 3250$ Å

$\lambda = 2536 \times 10^{-10}$ m $= 2536$ Å, $m = 9.1 \times 10^{-31}$ kg

$hc = 4.14 \times 10^{-15}$ eV s $\times 3 \times 10^8$ m s$^{-1} = 12420$ eV Å

$$\therefore \quad \frac{1}{2}mv^2 = 12420\left[\frac{1}{2536} - \frac{1}{3250}\right] \text{eV} = 1.076 \text{ eV}$$

$$v^2 = \frac{2.152 \text{ eV}}{m} = \frac{2.152 \times 1.6 \times 10^{-19}}{9.1 \times 10^{-31}}$$

$\therefore \quad v \approx 6 \times 10^5$ m s$^{-1} = 0.6 \times 10^6$ m s^{-1}

Note: Options (a) and (d) are same. So both are correct.

39. (d) : Work done in a coil

$W = mB(\cos\theta_1 - \cos\theta_2)$

When it is rotated by angle 180° then

$W = 2mB = 2(NIA)B$ ...(i)

Given: $N = 250$, $I = 85\ \mu A = 85 \times 10^{-6}$ A

$A = 1.25 \times 2.1 \times 10^{-4}$ m$^2 \approx 2.5 \times 10^{-4}$ m^2

$B = 0.85$ T

Putting these values in eqn. (i), we get

$W = 2 \times 250 \times 85 \times 10^{-6} \times 2.5 \times 10^{-4} \times 0.85$

$\approx 9.1 \times 10^{-6}$ J $= 9.1\ \mu$J

40. (b) : The wavelength of last line of Balmer series

$$\frac{1}{\lambda_B} = Rc\left(\frac{1}{2^2} - \frac{1}{\infty^2}\right) = \frac{Rc}{4}$$

The wavelength of last line of Lyman series

$$\frac{1}{\lambda_L} = Rc\left(\frac{1}{1^2} - \frac{1}{\infty^2}\right) = Rc \quad \therefore \quad \frac{\lambda_B}{\lambda_L} = \frac{4}{1} = 4$$

41. (a) : The relation between coefficient of performance and efficiency of carnot engine is given as

$$\beta = \frac{1-\eta}{\eta}; \text{ Given } \eta = \frac{1}{10}, \ W = 10 \text{ J}$$

$$\beta = \frac{1 - \frac{1}{10}}{\frac{1}{10}} = \frac{9}{10}.10 = 9$$

Since, $\beta = \frac{Q_2}{W}$, where Q_2 is the amount of energy absorbed from the reservoir

$\therefore \quad Q_2 = \beta W = 9 \times 10 = 90$ J

42. (c) : The internal energy of 2 moles of O_2 atom is

$$U_{O_2} = \frac{n_1 f_1}{2}RT = 2 \times \frac{5}{2} \times RT = 5\,RT$$

The internal energy of 4 moles of Ar atom is

$$U_{Ar} = \frac{n_2 f_2 RT}{2} = 4 \times \frac{3}{2} \times RT = 6RT$$

$\therefore$ The total internal energy of the system is

$U = U_{O_2} + U_{Ar} = 5RT + 6RT = 11RT$

43. (c) : Force between wires A and B = force between wires B and C

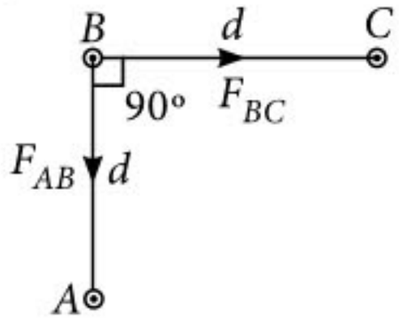
$$\therefore \ F_{BC} = F_{AB} = \frac{\mu_o I^2 l}{2\pi d}$$

As $\vec{F}_{AB} \perp \vec{F}_{BC}$, net force on wire B,

$$F_{net} = \sqrt{2}F_{BC} = \frac{\sqrt{2}\,\mu_o I^2 l}{2\pi d}$$

$$F_{net} = \frac{\mu_o I^2 l}{\sqrt{2}\,\pi d}$$

$$\text{or } \frac{F_{net}}{l} = \frac{\mu_o I^2}{\sqrt{2}\,\pi d}$$



44. (c) : Pressure at point C, $P_C = P_a + \rho_{water}\, g h_{water}$, where $h_{water} = CE = (65 + 65)$ mm $= 130$ mm

Pressure at point B, $P_B = P_a + \rho_{oil}\, g h_{oil}$

where $h_{oil} = AB = (65 + 65 + 10)$ mm $= 140$ mm

In liquid, pressure is same at same liquid level,

$P_B = P_C$; $\rho_{oil}\, g h_{oil} = \rho_{water}\, g\, h_{water}$

$$\rho_{oil} = \frac{130 \times 10^3}{140} = \frac{13}{14} \times 10^3 = 928.57 \text{ kg m}^{-3}$$

45. (*) : Centre of gravity of a body is the point at which the total gravitational torque on body is zero.

Centre of mass and centre of gravity coincides only for symmetrical bodies.

Hence statements (1) and (2) are incorrect.

A couple of a body produces rotational motion only.

Hence statement (3) is incorrect.

Mechanical advantage greater than one means that the system will require a force that is less than the load in order to move it.

Hence statement (4) is correct.

*None of the given options is correct.

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