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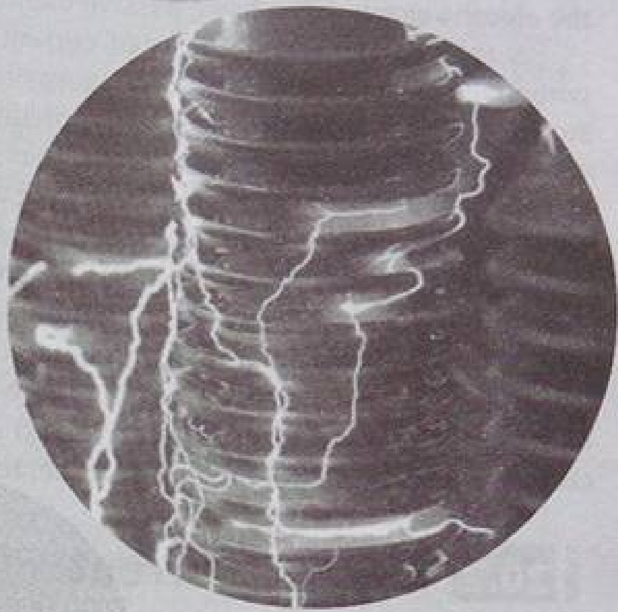


20

Current Electricity

Chapter Contents

Solved Examples

Example 1 *Two sources of current of equal emf are connected in series and have different internal resistances r_1 and r_2 $(r_2 > r_1)$. Find the external resistance R at which the potential difference across the terminals of one of the sources (which one in particular) becomes equal to zero.*

Solution

$$V = E - ir$$

E and i for both the sources are equal. Therefore, potential difference (V) will be zero for a source having greater internal resistance, *i.e.*, r_2.

$\therefore$

$$0 = E - ir_2$$

or

$$E = ir_2 = \left(\frac{2E}{R + r_1 + r_2}\right) \cdot r_2$$

$\therefore$

$$2r_2 = R + r_1 + r_2$$

or

$$R = r_2 - r_1$$ **Ans.**

Example 2

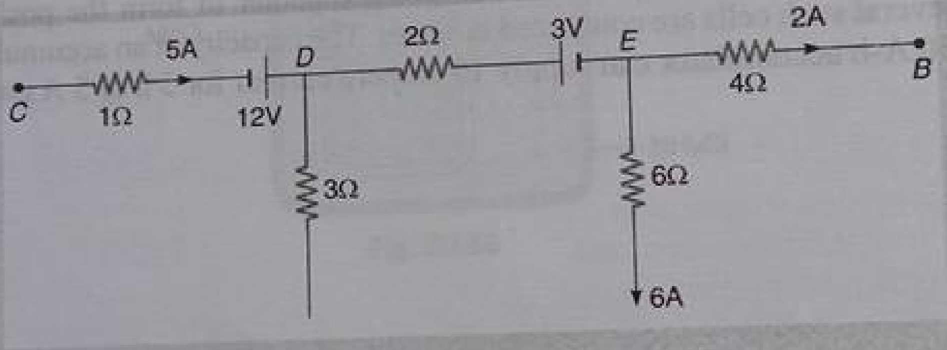


Fig. 20.89

Figure shows part of a circuit. Calculate the power dissipated in 3 Ω resistance. What is the potential difference $V_C - V_B$?

Solution Applying Kirchhoff's junction law at E current in wire DE is 8 A from D to E. Now further applying junction law at D. The current in 3 Ω resistance will be 3 A towards D.

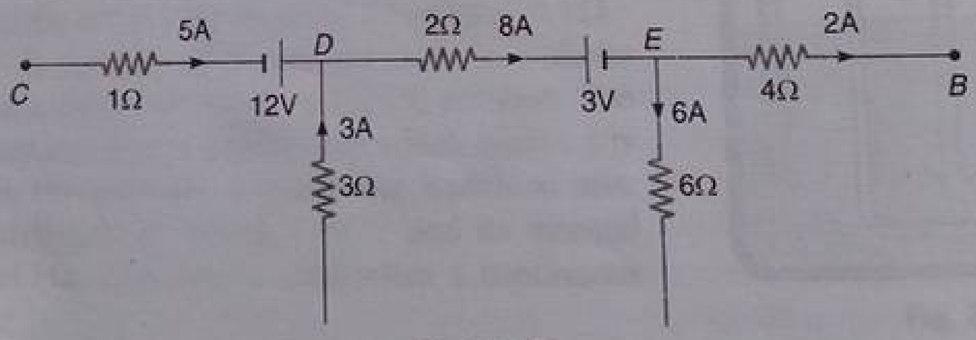


Fig. 20.90

$$\text{Power dissipated in } 3\,\Omega \text{ resistance} = i^2R = (3)^2\,(3)$$

$$= 27\text{ W}$$ **Ans.**

$V_C - V_B$:

$$V_C - 5\times1 + 12 - 8\times2 - 3 - 4\times2 = V_B$$

$\therefore$

$$V_C - V_B = 5 - 12 + 16 + 3 + 8$$

or

$$V_C - V_B = 20 \text{ volt}$$ **Ans.**

Example 3 *A battery has an open circuit potential difference of 6 V between its terminals. When a load resistance of 60 Ω is connected across the battery, the total power dissipated by the battery is 0.4 W. What should be the load resistance R, so that maximum power will be dissipated in R. Calculate this power. What is the total power supplied by the battery when such a load is connected?*

Solution When the circuit is open, $V = E$

$\therefore$ $E = 6$ V

Let r be the internal resistance of the battery.

Power supplied by the battery in this case is,

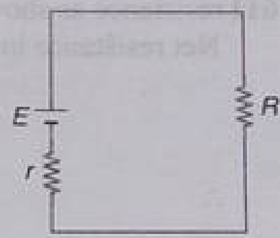


Fig. 20.91

$$P = \frac{E^2}{R + r}$$

Substituting the values, we have $0.4 = \dfrac{(6)^2}{60 + r}$

Solving this, we get $r = 30\,\Omega$.

Maximum power is dissipated in the circuit when, net external resistance is equal to net internal resistance or,

$$R = r$$

$\therefore$ $R = 30\,\Omega$ **Ans.**

Further, total power supplied by the battery under this condition is,

$$P_{\text{Total}} = \frac{E^2}{R + r} = \frac{(6)^2}{30 + 30}$$

$$= 0.6 \text{ W}$$ **Ans.**

Of this 0.6 W half of the power is dissipated in R and half in r. Therefore, maximum power dissipated in R would be

$$\frac{0.6}{2} = 0.3 \text{ W}$$ **Ans.**

Example 4 *In which branch of the circuit shown in figure a 11 V battery be inserted so that it dissipates minimum power. What will be the current through the 2Ω resistance for this position of the battery?*

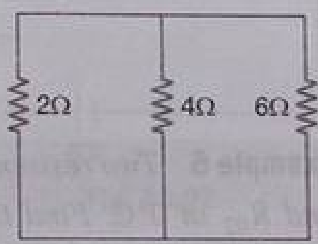


Fig. 20.92

Solution Suppose, we insert the battery with $2\,\Omega$ resistance. Then we can take $2\,\Omega$ as the internal resistance (r) of the battery and combined resistance of the other two as the external resistance (R). The circuit in that case shown in Fig. 20.93,

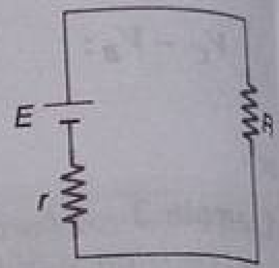


Fig. 20.93

Now power,
$$P = \frac{E^2}{R+r}$$

This power will be minimum where $R+r$ is maximum and we can see that $(R+r)$ will be maximum when the battery is inserted with $6\,\Omega$ resistance as shown in Fig. 20.94.

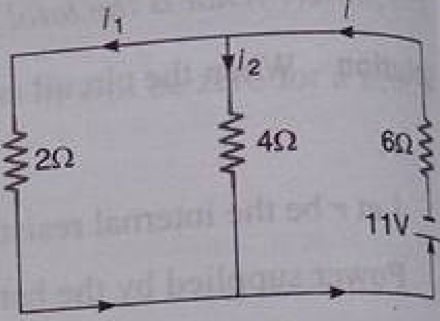


Fig. 20.94

Net resistance in this case is
$$6 + \frac{2\times 4}{2+4} = \frac{22}{3}\,\Omega$$

$\therefore$
$$i = \frac{11}{22/3} = 1.5\text{ A}$$

This current will be distributed in $2\,\Omega$ and $4\,\Omega$ in the inverse ratio of their resistances.

$\therefore$
$$\frac{i_1}{i_2} = \frac{4}{2} = 2$$

$\therefore$
$$i_1 = \left(\frac{2}{2+1}\right)(1.5) = 1.0\text{ A}$$ **Ans.**

Example 5 *The emf of a storage battery is 90 V before charging and 100 V after charging. When charging began the current was 10 A. What is the current at the end of charging if the internal resistance of the storage battery during the whole process of charging may be taken as constant and equal to $2\,\Omega$?*

Solution The voltage supplied by the charging plant is here constant which is equal to,
$$V = E_i + i_i \cdot r = (90) + (10)\,(2)$$
$$= 110\text{ V}$$

Let i_f be the current at the end of charging.

Then,
$$V = E_f + i_f r$$

or
$$i_f = \frac{V - E_f}{r} = \frac{110-100}{2}$$
$$= 5\text{ A}$$ **Ans.**

Example 6 *Two resistors with temperature coefficients of resistance α_1 and α_2 have resistances R_{01} and R_{02} at 0°C. Find the temperature coefficient of the compound resistor consisting of the two resistors connected,*

(a) in series *(b) in parallel.*

Solution In series :

Fig. 20.95

At 0°C	R_{01}	R_{02}	$R_0 = R_{01} + R_{02}$
At t°C	$R_{01}(1+\alpha_1 t)$	$R_{02}(1+\alpha_2 t)$	$R_0(1+\alpha t)$

$$R_{01}(1+\alpha_1 t) + R_{02}(1+\alpha_2 t) = R_0(1+\alpha t)$$

or $$R_{01}(1+\alpha_1 t) + R_{02}(1+\alpha_2 t) = (R_{01}+R_{02})(1+\alpha t)$$

∴ $$R_{01} + R_{01}\alpha_1 t + R_{02} + R_{02}\alpha_2 t = R_{01} + R_{02} + (R_{01}+R_{02})\alpha t$$

or $$\alpha = \frac{R_{01}\alpha_1 + R_{02}\alpha_2}{R_{01}+R_{02}}$$ **Ans.**

In parallel :

Fig. 20.96

At t°C, $$\frac{1}{R_0(1+\alpha t)} = \frac{1}{R_{01}(1+\alpha_1 t)} + \frac{1}{R_{02}(1+\alpha_2 t)}$$

or $$\frac{R_{01}+R_{02}}{R_{01}R_{02}(1+\alpha t)} = \frac{1}{R_{01}(1+\alpha_1 t)} + \frac{1}{R_{02}(1+\alpha_2 t)}$$

Using the Binomial expansion, we have

$$\frac{1}{R_{02}}(1-\alpha t) + \frac{1}{R_{01}}(1-\alpha t) = \frac{1}{R_{01}}(1-\alpha_1 t) + \frac{1}{R_{02}}(1-\alpha_2 t)$$

i.e., $$\alpha t\left(\frac{1}{R_{01}} + \frac{1}{R_{02}}\right) = \frac{\alpha_1}{R_{01}} t + \frac{\alpha_2}{R_{02}} t$$

or $$\alpha = \frac{\alpha_1 R_{02} + \alpha_2 R_{01}}{R_{01}+R_{02}}$$ **Ans.**

Example 7 *An ammeter and a voltmeter are connected in series to a battery with an emf $E = 6.0\,V$. When a certain resistance is connected in parallel with the voltmeter, the reading of the latter decreases two times, whereas the readings of the ammeter increase the same number of times. Find the voltmeter readings after the connection of the resistance.*

Solution Let R_1 = resistance of ammeter

and R_2 = combined resistance of ammeter and voltmeter

In the first case, current in the circuit,

$$i = \frac{6}{R_2} \qquad \text{...(i)}$$

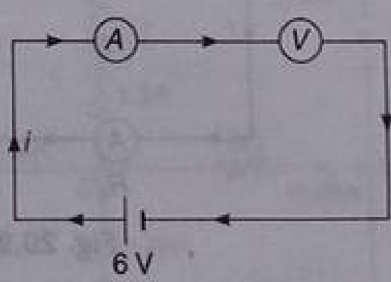


Fig. 20.97

and voltage across voltmeter $V = 6 -$ voltage across ammeter

or $$V = 6 - iR_1$$

or
$$V = 6 - \frac{6R_1}{R_2} \qquad \text{...(ii)}$$

In the second case, reading of ammeter becomes two times, *i.e.*, the total resistance becomes half while the resistance of ammeter remains unchanged. Hence,

$$i' = \frac{6}{R_2/2} = \frac{12}{R_2}$$

and
$$V' = 6 - (i')R_1$$

or
$$V' = 6 - \frac{12R_1}{R_2} \qquad \text{...(iv)}$$

Further, it is given that
$$V' = \frac{V}{2}$$

or
$$6 - \frac{12R_1}{R_2} = 3 - \frac{3R_1}{R_2}$$

or
$$\frac{R_1}{R_2} = \frac{1}{3}$$

Substituting this value in Eq. (iv), we have

$$V' = 6 - (12)\left(\frac{1}{3}\right)$$

or
$$V' = 2 \text{ volt}$$

Ans.

Example 8 *A voltmeter of resistance R_1 and an ammeter of resistance R_2 are connected in series across a battery of negligible internal resistance. When a resistance R is connected in parallel to voltmeter, reading of ammeter increases three times while that of voltmeter reduces to one third. Find R_1 and R_2 in terms of R.*

Solution Let E be the emf of the battery.

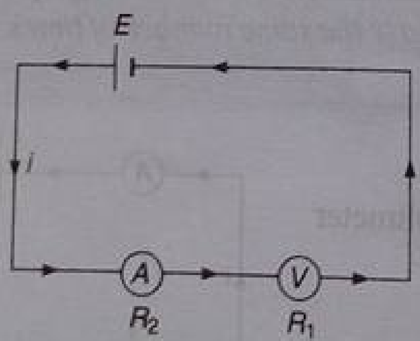


Fig. 20.98

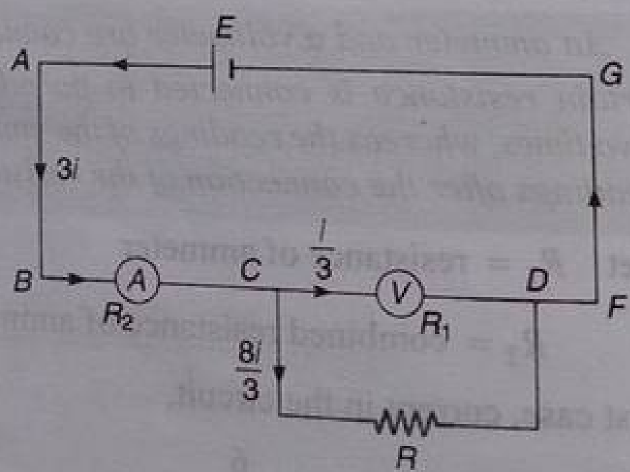


Fig. 20.99

In the first case, let i be the current in the circuit, then

$$E = i(R_1 + R_2) \qquad \text{...(i)}$$

In the second, case main current increases three times while current through voltmeter will reduce to $i/3$. Hence, the remaining $3i - i/3 = 8i/3$ passes through R as shown in figure.

$$V_C - V_D = \left(\frac{i}{3}\right) R_1 = \left(\frac{8i}{3}\right) R$$

or $$R_1 = 8R$$ **Ans.**

Applying Kirchhoff's second law in loop $ABFGA$,

$$E = 3i(R_2) + (i/3)(R_1) = i\left(3R_2 + \frac{R_1}{3}\right) \quad \text{...(ii)}$$

From Eqs. (i) and (ii), $$R_1 + R_2 = 3R_2 + \frac{R_1}{3}$$

or $$2R_2 = \frac{2R_1}{3}$$

or $$R_2 = \frac{R_1}{3}$$

or $$R_2 = \frac{8R}{3}$$ **Ans.**

Example 9 *Find the current in each branches of the circuit.*

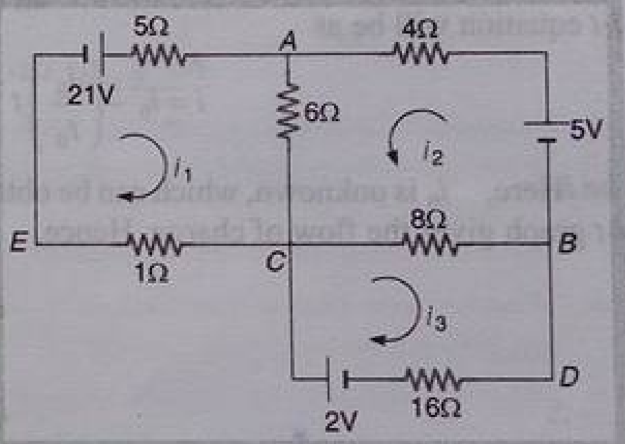


Fig. 20.100

Solution It is possible to use Kirchhoff's laws in a slightly different form, which may simplify the solution of certain problems. This method of applying Kirchhoff's laws is called the **loop current method.**

In this method we assign a current to every closed loop in a network.

Suppose currents i_1, i_2 and i_3 are flowing in the three loops. The clockwise or anticlockwise sense given to these currents is arbitrary. Applying Kirchhoff's second law to the three loops, we get

$$21 - 5i_1 - 6(i_1 + i_2) - i_1 = 0 \quad \text{...(i)}$$

$$5 - 4i_2 - 6(i_1 + i_2) - 8(i_2 + i_3) = 0 \quad \text{...(ii)}$$

and $$2 - 8(i_2 + i_3) - 16i_3 = 0 \quad \text{...(iii)}$$

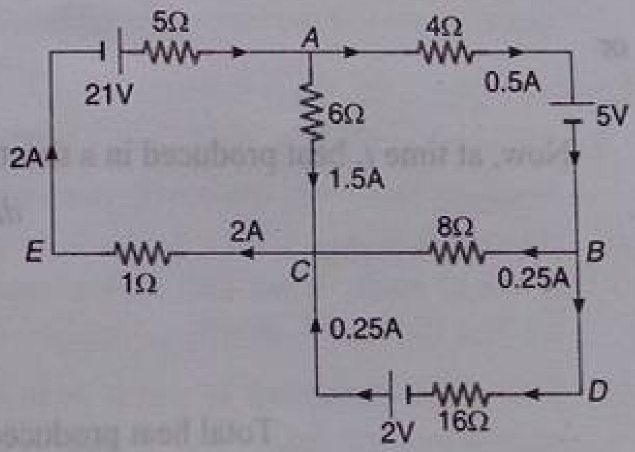


Fig. 20.101

Solving these three equations, we get

$$i_1 = 2\text{ A},\qquad i_2 = -\frac{1}{2}\text{ A}\qquad \text{and}\qquad i_3 = \frac{1}{4}\text{ A}$$

Therefore, current in different branches are as shown in Fig. 20.101.

Note *In wire AC, current is $i_1 + i_2$ and in CB it is $i_2 + i_3$. So, care has to be taken while applying the loop law.*

Example 10 *What amount of heat will be generated in a coil of resistance R due to a charge q passing through it if the current in the coil*
(a) decreases down to zero uniformly during a time interval t_0?
(b) decreases down to zero halving its value every t_0 seconds?

HOW TO PROCEED *Heat generated in a resistance is given by,*

$$H = i^2Rt$$

We can directly use this formula provided i is constant. Here, i is varying. So, first we will calculate i at any time t, then find a small heat dH in a short interval of time dt. Then by integrating it with proper limits we can obtain the total heat produced.

Solution (a) The corresponding *i-t* graph will be a straight line with *i* decreasing from a peak value (say i_0) to zero in time t_0.

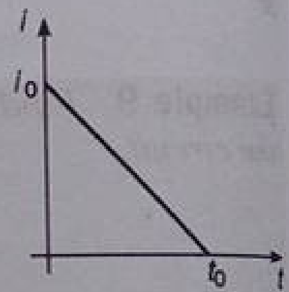


Fig. 20.102

i-t equation will be as

$$i = i_0 - \left(\frac{i_0}{t_0}\right)t \qquad (y = -mx + c) \qquad \ldots\text{(i)}$$

Here, i_0 is unknown, which can be obtained by using the fact that area under *i-t* graph gives the flow of charge. Hence,

$$q = \frac{1}{2}(t_0)(i_0)$$

$$\therefore \qquad i_0 = \frac{2q}{t_0}$$

Substituting in (i), we get,

$$i = \frac{2q}{t_0}\left(1 - \frac{t}{t_0}\right)$$

or

$$i = \left(\frac{2q}{t_0} - \frac{2qt}{t_0^2}\right)$$

Now, at time *t*, heat produced in a short interval *dt* is,

$$dH = i^2R\,dt$$

$$= \left(\frac{2q}{t_0} - \frac{2qt}{t_0^2}\right)^2 R\,dt$$

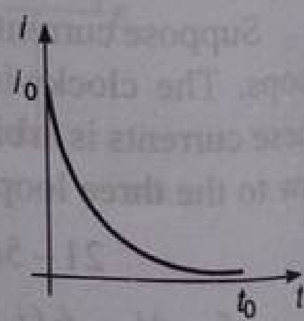


Fig. 20.103

$$\therefore \qquad \text{Total heat produced} = \int_0^{t_0} dH$$

or $$H = \int_0^{t_0} \left(\frac{2q}{t_0} - \frac{2qt}{t_0^2} \right)^2 R\, dt$$

$$= \frac{4}{3} \frac{q^2 R}{t_0}$$ **Ans.**

(b) Here, current decreases from some peak value (say i_0) to zero exponentially with half life t_0. i-t equation in this case will be

$$i = i_0 e^{-\lambda t}$$

Here, $$\lambda = \frac{\ln (2)}{t_0}$$

Now, $$q = \int_0^{\infty} i\, dt = \int_0^{\infty} i_0\, e^{-\lambda t}\, dt = \left(\frac{i_0}{\lambda} \right)$$

$\therefore$ $$i_0 = \lambda\, q$$

$\therefore$ $$i = (\lambda q)\, e^{-\lambda t}$$

$\therefore$ $$dH = i^2 R\, dt = \lambda^2 q^2 e^{-2\lambda t} R\, dt$$

or $$H = \int_0^{\infty} dH = \lambda^2 q^2 R \int_0^{\infty} e^{-2\lambda t}\, dt = \frac{q^2 \lambda R}{2}$$

Substituting $\lambda = \frac{\ln (2)}{t_0}$, we have $$H = \frac{q^2 R \ln (2)}{2t_0}.$$ **Ans.**

EXERCISES

AIEEE Corner

Subjective Questions (Level 1)

Note *You can take approximations in the answers.*

Current

1. How many electrons per second pass through a section of wire carrying a current of 0.7 A?
2. A current of 3.6 A flows through an automobile headlight. How many coulombs of charge flow through the headlight in 3.0 *h*?
3. A current of 7.5 A is maintained in wire for 45 s. In this time
   (a) How much charge and
   (b) How many electrons flow through the wire?
4. In the Bohr model, the electron of a hydrogen atom moves in a circular orbit of radius 5.3×10^{-11} m with a speed of 2.2×10^{6} m/s. Determine its frequency f and the current I in the orbit.
5. The current in a wire varies with time according to the relation $I = 55A - (0.65\ \text{A/s}^2)t^2$.
   (a) How many coulombs of charge pass a cross-section of the wire in the time interval between $t = 0$ and $t = 8.0$ s?
   (b) What constant current would transport the same charge in the same time interval?
6. When a wire carries a current of 1.20 A, the drift velocity is 1.20×10^{-4} m/s. What is the drift velocity when the current is 6.00 A?
7. Find the velocity of charge leading to 1 A current which flows in a copper conductor of cross-section 1 cm^2 and length 10 km. Free electron density of copper is $8.5\times10^{28}/\text{m}^3$. How long will it take the electric charge to travel from one end of the conductor to the other?
8. A typical copper wire have 2×10^{21} free electrons in 1 cm of its length. Suppose that the drift speed of the electrons along the wire is 0.05 cm/s. How many electrons would pass through a given cross-section of the wire each second? How large a current would be flowing in the wire?

Resistivity and Resistance

9. In household wiring, copper wire 2.05 mm in diameter is often used. Find the resistance of a 24.0 m length of this wire. Resistivity of copper is 0.017 μΩ-m.
10. You need to produce a set of cylindrical copper wires 3.50 m long that will have a resistance of 0.125 Ω each. What will be the mass of each of these wires? Specific resistance of copper $= 1.72\times10^{-8}$ Ω-m, density of copper $= 8.9\times10^{3}$ kg/m^3.
11. Two coils connected in series have resistance of 600 Ω and 300 Ω at 20 °C and temperature co-efficient of 0.001 and 0.004(°C)$^{-1}$ respectively. Find resistance of the combination at a temperature of 50°C. What is the effective temperature co-efficient of combination?

12. An aluminium wire 7.5 m long is connected in parallel with a copper wire 6 m long. When a current of 5 A is passed through the combination, it is found that the current in the aluminium wire is 3 A. The diameter of the aluminium wire is 1 mm. Determine the diameter of the copper wire. Resistivity of copper is 0.017 μΩ-m and that of the aluminium is 0.028 μΩ-m.

13. The potential difference between two points in a wire 75.0 cm apart is 0.938 V, when the current density is 4.40×10^{7} A/m^{2}. What is
(a) The magnitue of $\vec{E}$ in the wire?
(b) The resistivity of the material of which the wire is made?

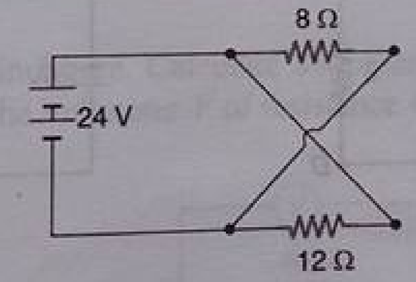
14. A rectangular block of metal of resistivity ρ has dimensions $d \times 2d \times 3d$. A potential difference V is applied between two opposite faces of the block.
(a) To which two faces of the block should the potential difference V be applied to give the maximum current density? What is the maximum current density?
(b) To which two faces of the block should the potential difference V be applied to give the maximum current? What is this maximum current?

15. An electrical conductor designed to carry large currents has a circular cross-section 2.50 mm in diameter and is 14.0 m long. The resistance between its ends is 0.104 Ω.
(a) What is the resistivity of the material?
(b) If the electric field magnitude in the conductor is 1.28 V/m, what is the total current?
(c) If the material has 8.5×10^{28} free electrons per cubic metre, find the average drift speed under the conditions of part (b).

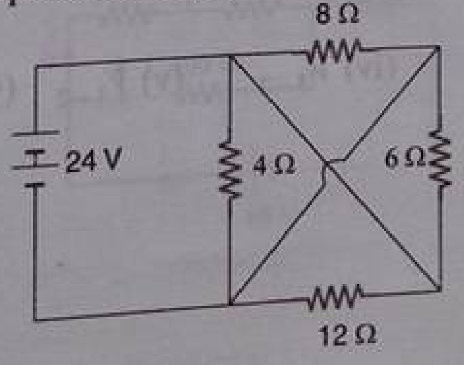
16. It is desired to make a 20.0 Ω coil of wire which has a zero thermal coefficient of resistance. To do this, a carbon resistor of resistance R_1 is placed in series with an iron resistor of resistance R_2. The proportions of iron and carbon are so chosen that $R_1 + R_2 = 20.00\ \Omega$ for all temperatures near 20°C. How large are R_1 and R_2? Given $\alpha_C = -0.5 \times 10^{-3}$ K^{-1} and $\alpha_{Fe} = 5.0 \times 10^{-3}$ K^{-1}.

Resistors in Series and Parallel (Kirchhoff's Laws)

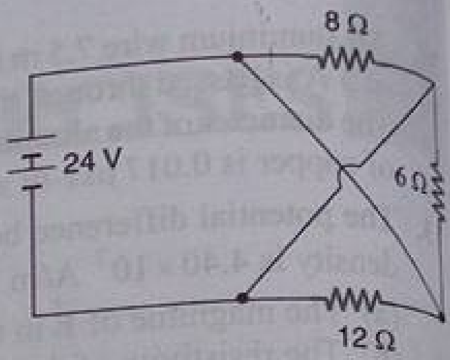
17. Find the current supplied by the battery in the circuit shown in figure.



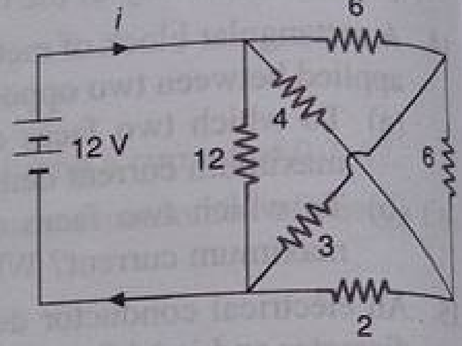
18. Calculate battery current and equivalent resistance of the network shown in figure.



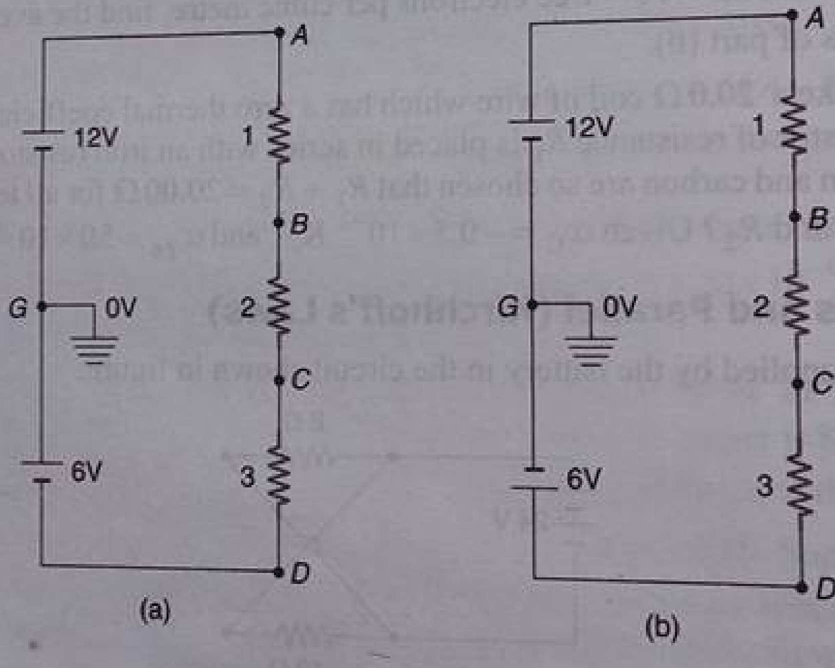
19. Compute total circuit resistance and battery current as shown in figure.



20. Compute the value of battery current i shown in figure. All resistances are in ohm.

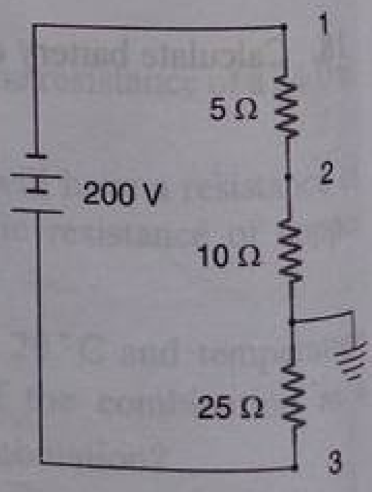


21. Calculate the potentials of points A, B, C and D as shown in figure (a). What would be the new potential values if connections of 6 V battery are reversed as shown in figure (b)? All resistances are in ohm.

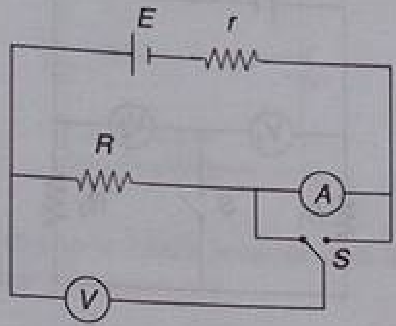


22. Give the magnitude and polarity of the following voltages in the circuit of figure :

(i) V_1 (ii) V_2 (iii) V_3 (iv) V_{3-2} (v) V_{1-2} (vi) V_{1-3}



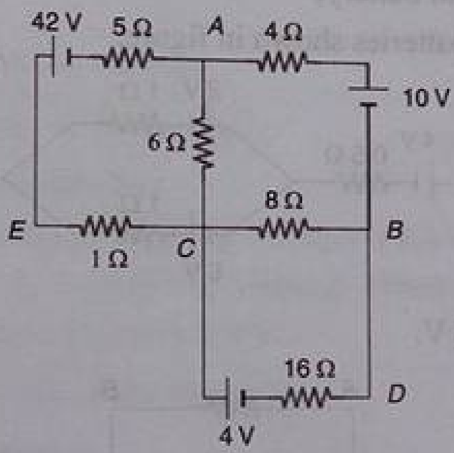
23. The emf E and the internal resistance r of the battery shown in figure are 4.3 V and 1.0 Ω respectively. The external resistance R is 50 Ω. The resistances of the ammeter and voltmeter are 2.0 Ω and 200 Ω respectively.



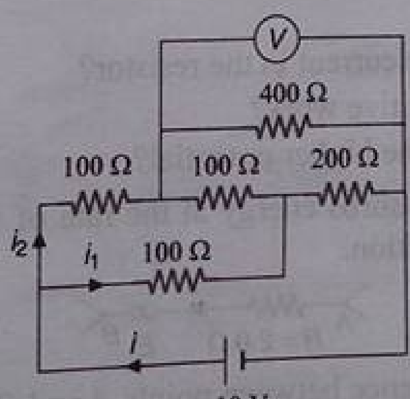
(a) Find the readings of the two meters.

(b) The switch is thrown to the other side. What will be the readings of the two meters now?

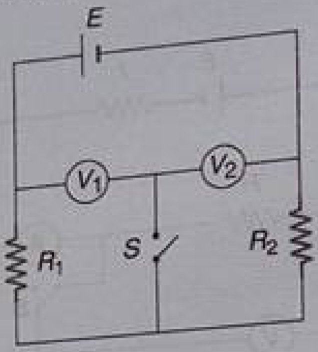
24. Find the current in each branch of the circuit shown in figure.



25. An electrical circuit is shown in figure. Calculate the potential difference across the resistor of 400 Ω as will be measured by the voltmeter V of resistance 400 Ω either by applying Kirchhoff's rules or otherwise.



26. In the circuit shown in figure V_1 and V_2 are two voltmeters of resistances $3000\,\Omega$ and $2000\,\Omega$ respectively. In addition $R_1 = 2000\,\Omega$, $R_2 = 3000\,\Omega$ and $E = 200$ V.



(a) Find the reading of voltmeters V_1 and V_2 when

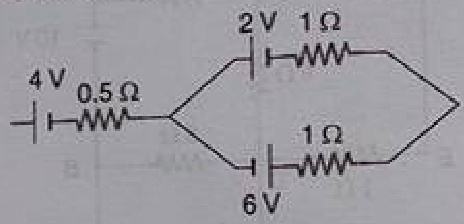
(i) switch S is open

(ii) switch S is closed

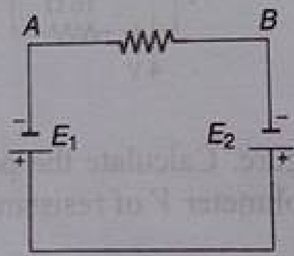
(b) Current through S, when it is closed

(Disregard the resistance of battery)

27. Find the net emf of the three batteries shown in figure.



28. In figure $E_1 = 12$ V and $E_2 = 8$ V.

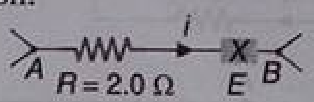


(a) What is the direction of the current in the resistor?

(b) Which battery is doing positive work?

(c) Which point, A or B, is at the higher potential?

29. In figure, circuit section AB absorbs energy at the rate of 5.0 W when a current $i = 1.0$ A passes through it in the indicated direction.

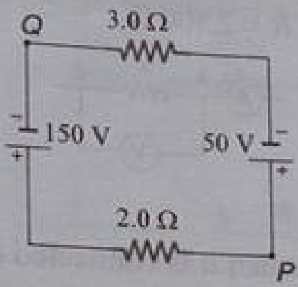


(a) What is the potential difference between points A and B?

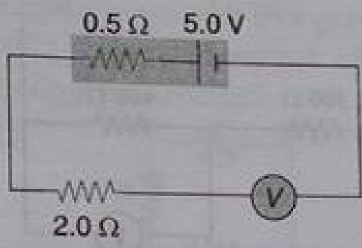
(b) Emf device X does not have internal resistance. What is its emf?

(c) What is its polarity (the orientation of its positive and negative terminals)?

30. In figure, if the potential at point P is 100 V, what is the potential at point Q?



31. An ideal voltmeter V is connected to a 2.0 Ω resistor and a battery with emf 5.0 V and internal resistance 0.5 Ω as shown in figure :



(a) What is the current in the 2.0 Ω resistor?

(b) What is the terminal voltage of the battery?

(c) What is the reading of the voltmeter?

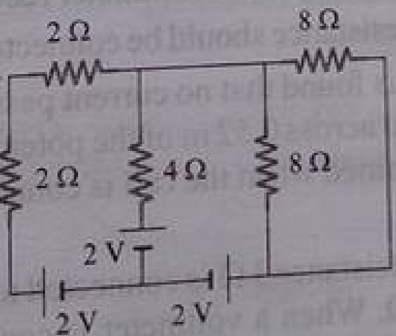
32. The potential difference across the terminals of a battery is 8.4 V when there is a current of 1.50 A in the battery from the negative to the positive terminal. When the current is 3.50 A in the reverse direction, the potential difference becomes 9.4 V.

(a) What is the internal resistance of the battery?

(b) What is the emf of the battery?

33. A battery of emf 2.0 V and internal resistance 0.10 Ω is being charged with a current of 5.0 A. Find the potential difference between the terminals of the battery?

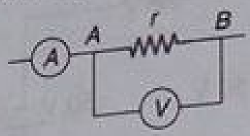
34. Find the currents in different resistors shown in figure.



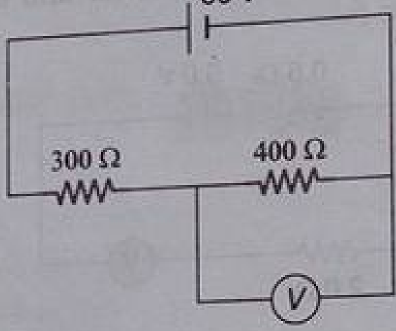
Electrical Measuring Instruments

35. A resistance box, a battery and a galvanometer of resistance G ohm are connected in series. If the galvanometer is shunted by resistance of S ohm, find the change in resistance in the box required to maintain the current from the battery unchanged.

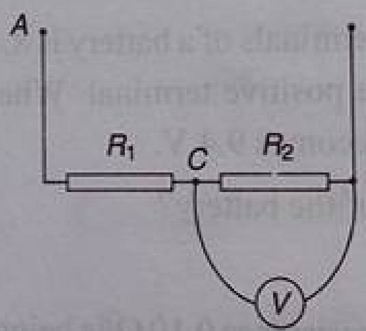
36. Determine the resistance r if an ammeter shows a current of $I = 5$ A and a voltmeter 100 V. The internal resistance of the voltmeter is $R = 2{,}500\ \Omega$.



37. In the circuit, a voltmeter reads 30 V when it is connected across 400 Ω resistance. Calculate what the same voltmeter will read when it is connected across the 300Ω resistance?



38. Resistances R_1 and R_2, each 60 Ω, are connected in series. The potential difference between points A and B is 120 V. Find the reading of voltmeter connected between points C and D if its resistance $r = 120\ \Omega$.

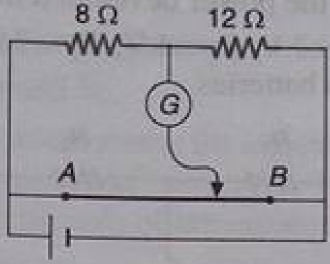


39. A moving coil galvanometer of resistance 20 Ω gives a full scale deflection when a current of 1 mA is passed through it. It is to be converted into an ammeter reading 20 A on full scale. But the shunt of 0.005 Ω only is available. What resistance should be connected in series with the galvanometer coil?

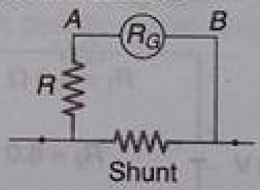
40. In a potentiometer experiment it is found that no current passes through the galvanometer when the terminals of the cell are connected across 0.52 m of the potentiometer wire. If the cell is shunted by a resistance of 5 Ω a balance is obtained when the cell is connected across 0.4 m of the wire. Find the internal resistance of the cell.

41. A cell of emf 3.4 V and internal resistance 3 Ω is connected to an ammeter having resistance 2 Ω and to an external resistance of 100 Ω. When a voltmeter is connected across the 100 Ω resistance the ammeter reading is 0.04 A. Find the voltage read by the voltmeter and its resistance. Had the voltmeter been an ideal one what would have been its reading?

42. The potentiometer wire AB shown in figure is 40 cm long. Where the free end of the galvanometer should be connected on AB so that the galvanometer may show zero deflection?



43. The resistance R_G of the coil of a pivoted-coil galvanometer is 9.36 Ω and a current of 0.0224 A causes it to deflect full scale. We want to convert this galvanometer to an ammeter reading 20.0 A full scale. The only shunt available has a resistance of 0.0250 Ω. What resistance R must be connected in series with the coil of galvanometer?

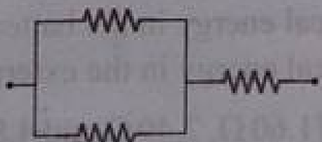


44. (a) A voltmeter with resistance R_V is connected across the terminals of a battery of emf E and internal resistance r. Find the potential difference measured by the voltmeter.
    (b) If $E = 7.50$ V and $r = 0.45\ \Omega$, find the minimum value of the voltmeter resistance R_V so that the voltmeter reading is within 1.0% of the emf of the battery.
    (c) Explain why your answer in part (b) represents a minimum value.

45. (a) An ammeter with resistance R_A is connected in series with a resistor R and a battery of emf ε and internal resistance r. The current measured by the ammeter is I_A. Find the current through the circuit if the ammeter is removed so that the battery and the resistor form a complete circuit. Express your answer in terms of I_A, r, R_A and R. The more "ideal" the ammeter, the smaller the difference between this current and the current I_A.
    (b) If $R = 3.80\ \Omega$, $\varepsilon = 7.50$ V and $r = 0.45\ \Omega$, find the maximum value of the ammeter resistance R_A so that I_A is within 99% of the current in the circuit when the ammeter is absent.
    (c) Explain why your answer in part (b) represents a maximum value.

Heating Effects of Current

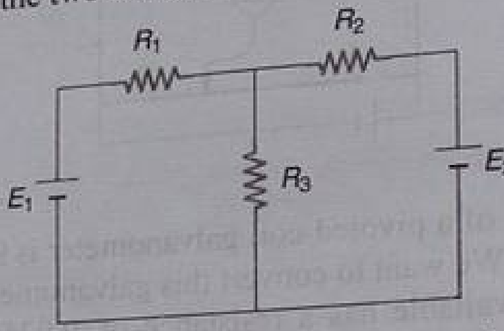
46. Each of three resistors in figure has a resistance of 2.4 Ω and can dissipate a maximum of 36 W without becoming excessively heated. What is the maximum power the circuit can dissipate?



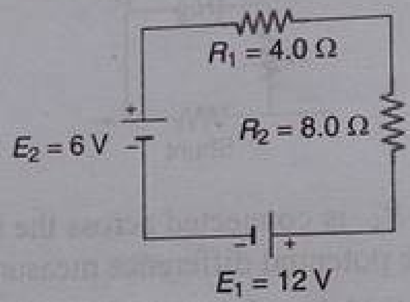
47. A 120 V house circuit has the following light bulbs switched on : 40 W, 60 W and 75 W. Find the equivalent resistance of these bulbs.

48. A storage battery with emf 2.6 V loaded with external resistance produces a current 1 A. In this case the potential difference between the terminals of the storage battery equals 2 V. Find the thermal power generated in the battery and the power developed in it by electric forces.

49. In the circuit shown in figure $E_1 = 7$ V, $E_2 = 1$ V, $R_1 = 2\,\Omega$, $R_2 = 2\,\Omega$ and $R_3 = 3\,\Omega$ respectively. Find the power supplied by the two batteries.



50. Assume that the batteries in figure have negligible internal resistance. Find :

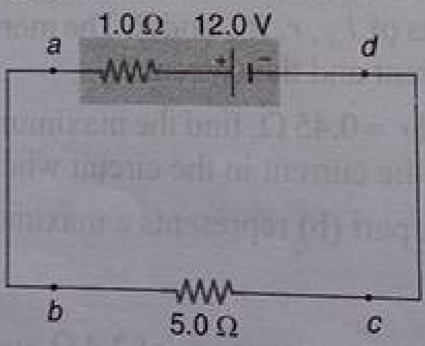


(a) the current in the circuit,

(b) the power dissipated in each resistor and

(c) the power of each battery, stating whether energy is supplied by or absorbed by it.

51. In the circuit shown in figure, find :



(a) the rate of conversion of internal (chemical) energy to electrical energy within the battery

(b) the rate of dissipation of electrical energy in the battery

(c) the rate of dissipation of electrical energy in the external resistor.

52. Three resistors having resistances of $1.60\,\Omega$, $2.40\,\Omega$ and $4.80\,\Omega$ are connected in parallel to a 28.0 V battery that has negligible internal resistance. Find :

(a) the equivalent resistance of the combination

(b) the current in each resistor

(c) the total current through the battery

(d) the voltage across each resistor

(e) the power dissipated in each resistor.

(f) which resistor dissipates the maximum power the one with the greatest resiśtance or the least resistance? Explain why this should be.

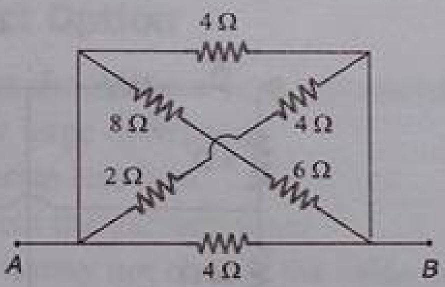
53. (a) The power of resistor is the maximum power the resistor can safely dissipate without too rise in temperature. The power rating of a 15 kΩ resistor is 5.0 W. What is the maximum allowable potential difference across the terminals of the resistor?

(b) A 9.0 kΩ resistor is to be connected across a 120 V potential difference. What power rating is required?

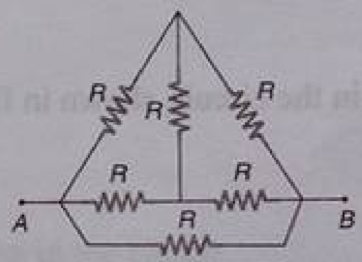
Equivalent Resistance

Note *Attempt this after reading article* 22.9.

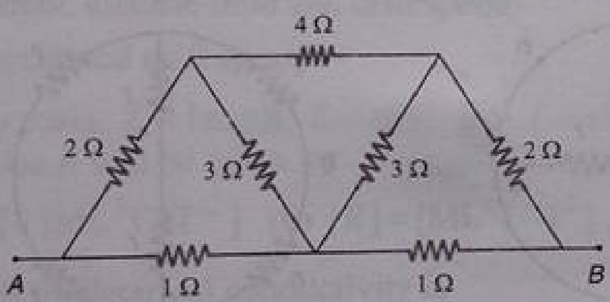
54. Find the equivalent resistance between points A and B in the following circuits :



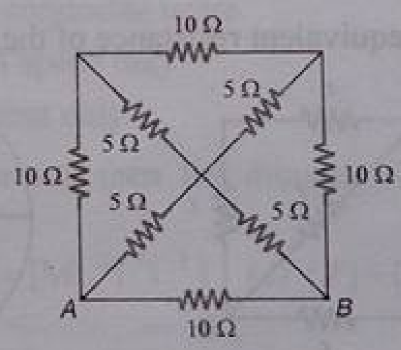
(a)



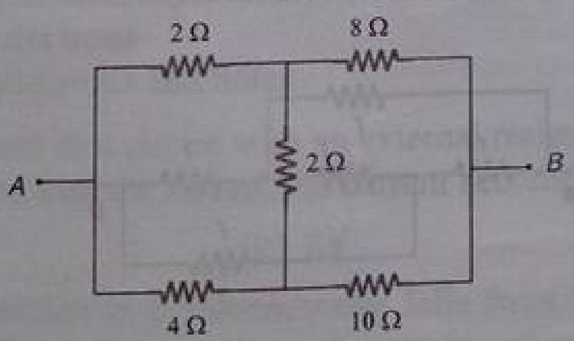
(b)



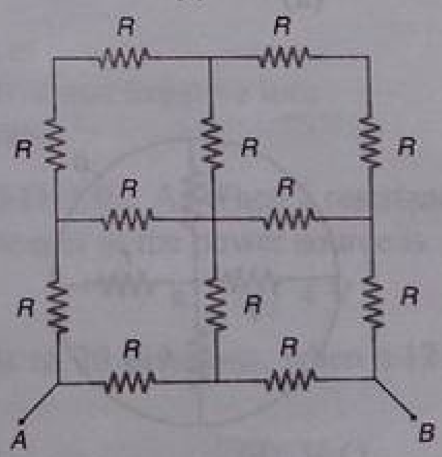
(c)



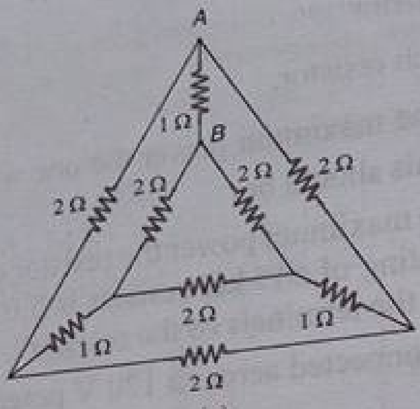
(d)



(e)

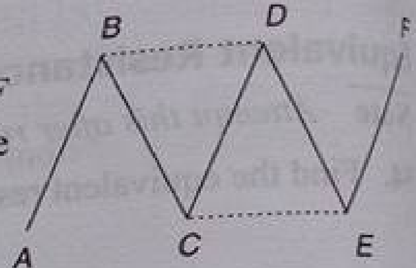


(f)

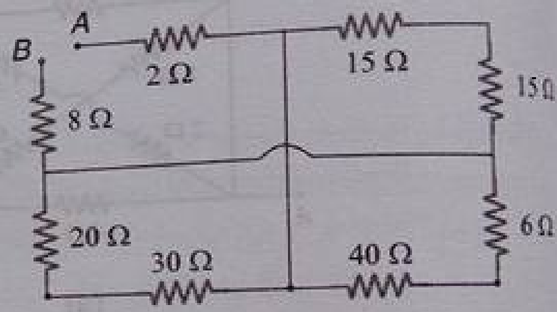


(g)

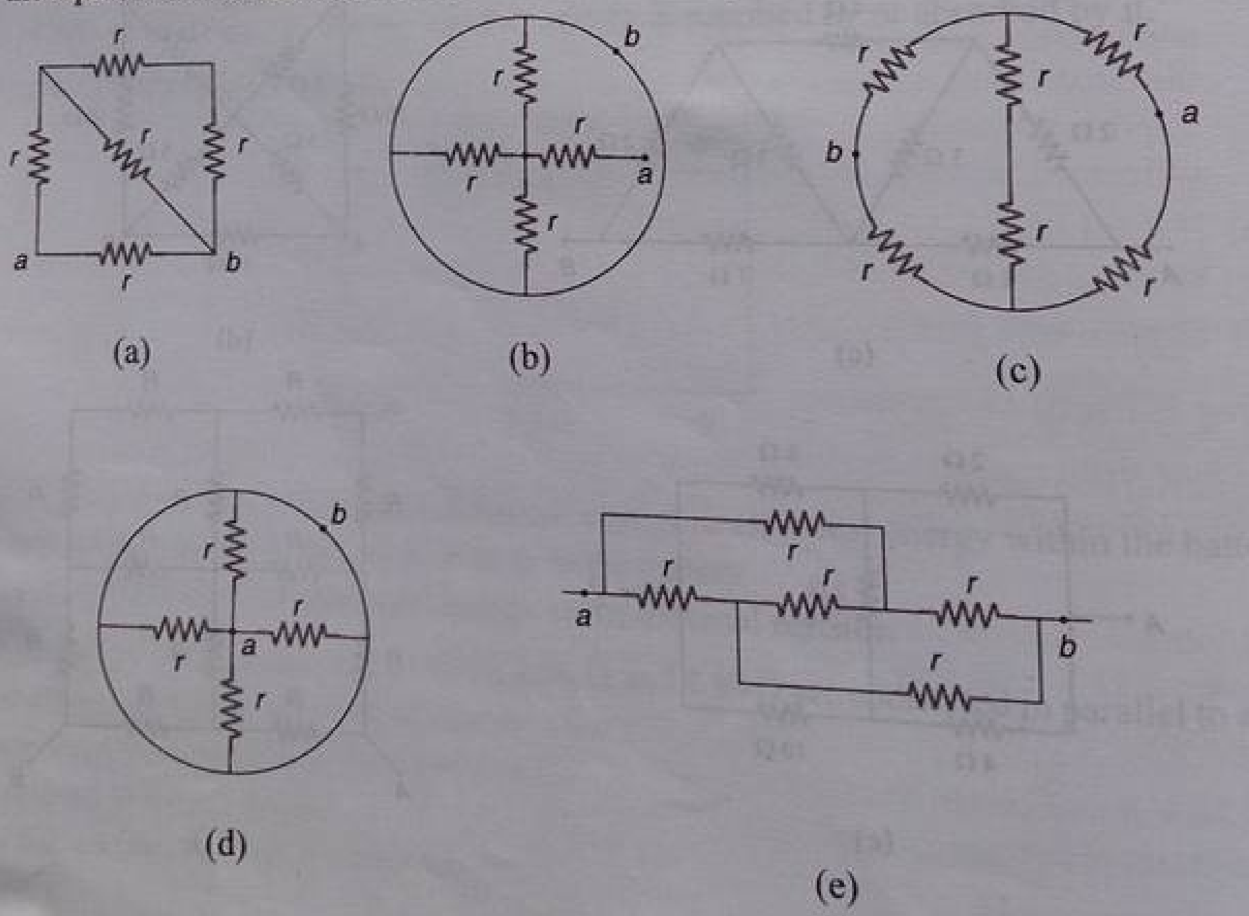
55. What will be the change in the resistance of a circuit between A and F consisting of five identical conductors, if two similar conductors are added as shown by the dashed line in figure?



56. Find R_{AB} in the circuit, shown in figure.



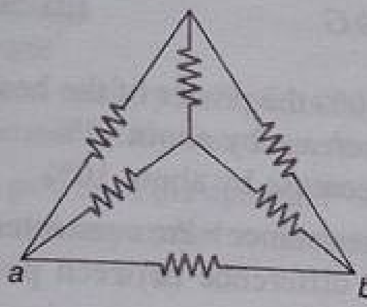
57. Find the equivalent resistance of the networks shown in figure between the points a and b.



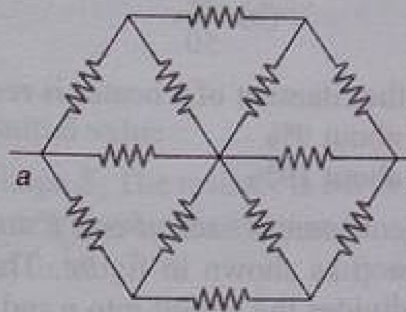
(a)　(b)　(c)

(d)　(e)

58. Find the equivalent resistance of the circuits shown in figure between the points a and b. Each resistor has a resistance r.



(a)



(b)

Objective Questions (Level 1)

Single Correct Option

1. An ammeter should have very low resistance
   (a) to show large deflection
   (b) to generate less heat
   (c) to prevent the galvanometer
   (d) so that it may not change the value of the actual current in the circuit

2. A steady current flows in a metallic conductor of non-uniform cross-section. The quantity/quantities which remain constant along the length of the conductor is/are
   (a) current, electric field and drift speed (b) drift speed only
   (c) current and drift speed (d) current only

3. If M = mass, L = length, T = time and I = electric current, then the dimensional formula of resistance R will be given by
   (a) $[R]=[ML^2T^{-3}I^{-2}]$ (b) $[R]=[ML^2T^{-3}I^2]$ (c) $[R]=[ML^2T^3I^{-2}]$ (d) $[R]=[ML^2T^3I^2]$

4. The unit of electrical conductivity is
   (a) ohm-m^{-2} (b) ohm × m (c) ohm^{-1}-m^{-1} (d) None of these

5. Through an electrolyte an electrical current is due to drift of
   (a) free electrons (b) positive and negative ions
   (c) free electrons and holes (d) protons

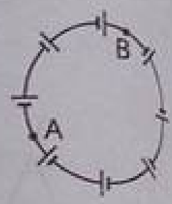
6. The current in a circuit with an external resistance of $3.75\,\Omega$ is 0.5 A. When a resistance of $1\,\Omega$ is introduced into the circuit, the current becomes 0.4 A. The emf of the power source is
   (a) 1V (b) 2V (c) 3 V (d) 4 V

7. The deflection in a galvanometer falls from 50 divisions to 20 divisions, when a $12\,\Omega$ shunt is applied. The galvanometer resistance is
   (a) $18\,\Omega$ (b) $24\,\Omega$ (c) $30\,\Omega$ (d) $36\,\Omega$

8. If 2% of the main current is to be passed through the galvanometer of resistance G, the resistance of shunt required is
   (a) $\frac{G}{49}$ (b) $\frac{G}{50}$ (c) $49\,G$ (d) $50\,G$

9. If the length of the filament of a heater is reduced by 10% the power of the heater will
   (a) increase by about 9% (b) increase by about 11%
   (c) increase by about 19% (d) decrease by about 10%

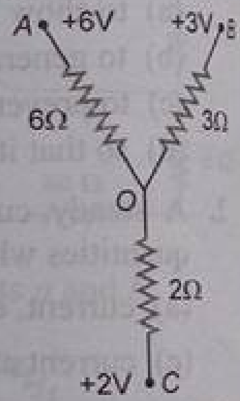
10. N identical current sources each of emf E and internal resistance r are connected to form a closed loop as shown in figure. The potential difference between points A and B which divides the circuit into n and $(N - n)$ units is



   (a) NE (b) $(N - n)E$
   (c) nE (d) zero

11. A 2.0 V potentiometer is used to determine the internal resistance of a 1.5 V cell. The balance point of the cell in the open circuit is 75 cm. When a resistor of 10 Ω is connected across the cell, the balance point shifts to 60 cm. The internal resistance of the cell is
   (a) 1.5 Ω (b) 2.5 Ω (c) 3.5 Ω (d) 4.5 Ω

12. Three resistances are joined together to form a letter Y, as shown in figure. If the potentials of the terminals A, B and C are 6 V, 3 V and 2 V respectively, then the potential of the point O will be

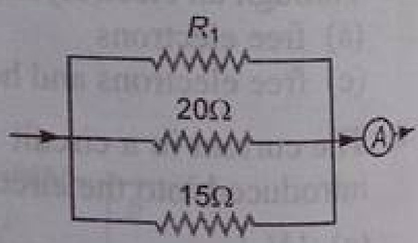


   (a) 4 V
   (b) 3 V
   (c) 2.5 V
   (d) 0 V

13. The drift velocity of free electrons in a conductor is v, when a current i is flowing in it. If both the radius and current are doubled, then the drift velocity will be
   (a) v (b) $v/2$ (c) $v/4$ (d) $v/8$

14. A galvanometer is to be converted into an ammeter or voltmeter. In which of the following cases the resistance of the device is largest ?
   (a) an ammeter of range 10 A (b) a voltmeter of range 5 V
   (c) an ammeter of range 5 A (d) a voltmeter of range 10 V

15. In the given circuit the current flowing through the resistance 20 Ω is 0.3 A, while the ammeter reads 0.8 A. What is the value of R_1?



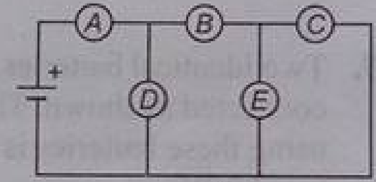
   (a) 30 Ω
   (b) 40 Ω
   (c) 50 Ω
   (d) 60 Ω

16. An ammeter and a voltmeter are joined in series to a cell. Their readings are A and V respectively. If a resistance is now joined in parallel with the voltmeter
   (a) both A and V will increase (b) both A and V will decrease
   (c) A will decrease, V will increase (d) A will increase, V will decrease

17. A voltmeter and an ammeter are joined in series to an ideal cell, giving readings V and A respectively. If a resistance equal to the resistance of the ammeter is now joined in parallel to the ammeter.
(a) V will not change
(b) V will increase
(c) A will become exactly half of its initial value
(d) A will become slightly less than double of its initial value

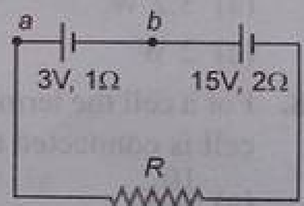
18. A resistor R has power of dissipation P with cell voltage E. The resistor is cut in n equal parts and all parts are connected in parallel with same cell. The new power dissipation is
(a) nP (b) nP^2 (c) n^2P (d) n/P

19. In the circuit diagram shown in figure, a fuse bulb can cause all other bulbs to go out. Identify the bulb



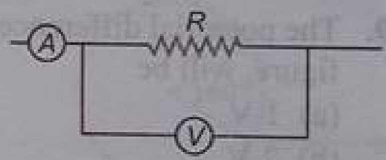
(a) B
(b) C
(c) A
(d) D or E

20. Two batteries one of the emf 3 V, internal resistance 1 Ω and the other of emf 15 V, internal resistance 2 Ω are connected in series with a resistance R as shown. If the potential difference between points a and b is zero, the resistance R in Ω is



(a) 5 (b) 7
(c) 3 (d) 1

21. A part of a circuit is shown in figure. Here reading of ammeter is 5 A and voltmeter is 100 V. If voltmeter resistance is 2500 ohm, then the resistance R is approximately

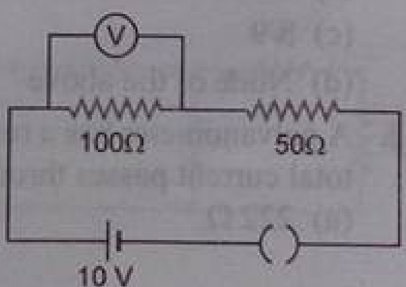


(a) 20 Ω (b) 10 Ω
(c) 100 Ω (d) 200 Ω

22. A copper wire of resistance R is cut into ten parts of equal length. Two pieces each are joined in series and then five such combinations are joined in parallel. The new combination will have a resistance
(a) R (b) $\frac{R}{4}$ (c) $\frac{R}{5}$ (d) $\frac{R}{25}$

23. Two resistances are connected in two gaps of a metre bridge. 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 Ω is
(a) 3 (b) 6 (c) 9 (d) 12

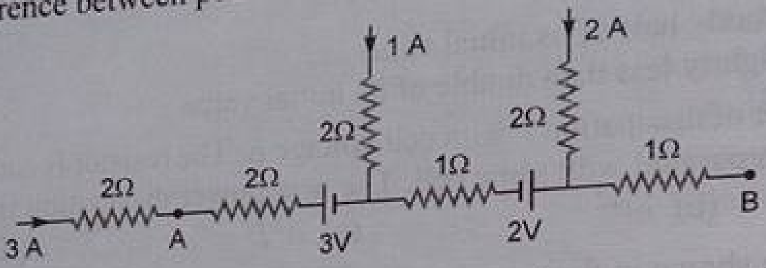
24. In the given circuit, the voltmeter records 5 volt. The resistance of the voltmeter in Ω is



(a) 200
(b) 100
(c) 10
(d) 50

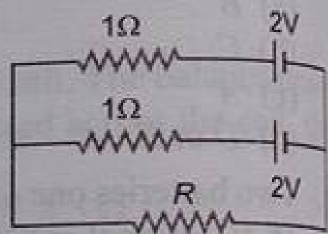
25. The wire of potentiometer has resistance $4\,\Omega$ and length 1 m. It is connected to a cell of emf 2 volt and internal resistance $1\,\Omega$. If a cell of emf 1.2 volt is balanced by it, the balancing length will be
(a) 90 cm (b) 60 cm (c) 50 cm (d) 75 cm

26. The potential difference between points A and B, in a section of a circuit shown, is



(a) 5 volt (b) 1 volt (c) 10 volt (d) 17 volt

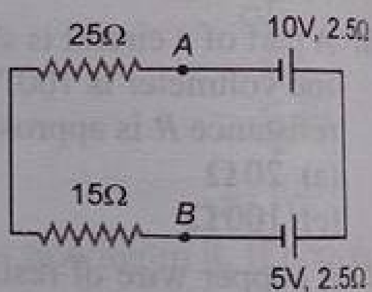
27. Two identical batteries, each of emf 2 V and internal resistance $r = 1\,\Omega$ are connected as shown. The maximum power that can be developed across R using these batteries is



(a) 3.2 W (b) 8.2 W
(c) 2 W (d) 4 W

28. For a cell the terminal potential difference is 2.2 V, when circuit is open and reduces to 1.8 V. When cell is connected to a resistance $R = 5\Omega$, the internal resistance of cell (r) is
(a) $\frac{10}{9}\Omega$ (b) $\frac{9}{10}\Omega$ (c) $\frac{11}{9}\Omega$ (d) $\frac{5}{9}\Omega$

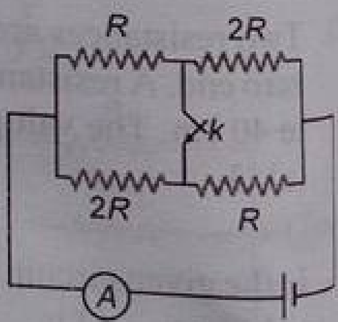
29. The potential difference between points A and B in the circuit shown in figure, will be



(a) 1 V
(b) 2 V
(c) −3 V
(d) −4 V

30. Potentiometer wire of length 1 m is connected in series with $490\,\Omega$ resistance and 2 V battery. If 0.2 mV/cm is the potential gradient, then resistance of the potentiometer wire is approximately
(a) $4.9\,\Omega$ (b) $7.9\,\Omega$ (c) $5.9\,\Omega$ (d) $6.9\,\Omega$

31. Find the ratio of currents as measured by ammeter in two cases when the key is open and when the key is closed



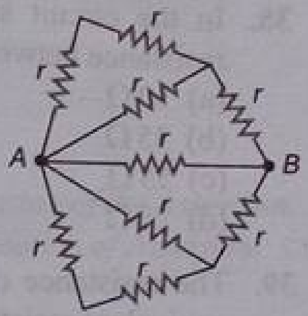
(a) 9/8
(b) 10/11
(c) 8/9
(d) None of the above

32. A galvanometer has a resistance of $3663\,\Omega$. A shunt S is connected across it such that (1/34) of the total current passes through the galvanometer. Then the value of the shunt is
(a) $222\,\Omega$ (b) $111\,\Omega$ (c) $11\,\Omega$ (d) $22\,\Omega$

Equivalent Resistance Problems

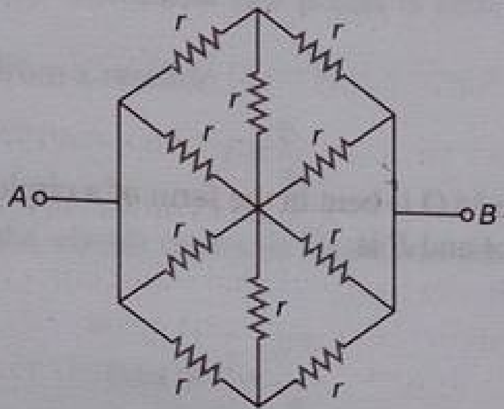
Note *Attempt these questions after reading article 22.9.*

33. The network shown in figure is an arrangement of nine identical resistors. The resistance of the network between points A and B is $1.5\,\Omega$. The resistance r is



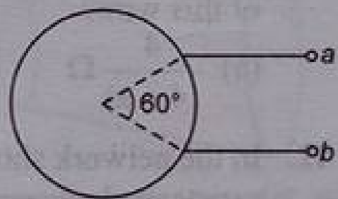
(a) $1.1\,\Omega$
(b) $3.3\,\Omega$
(c) $1.4\,\Omega$
(d) $1.8\,\Omega$

34. The equivalent resistance of the hexagonal network as shown in figure, between points A and B is



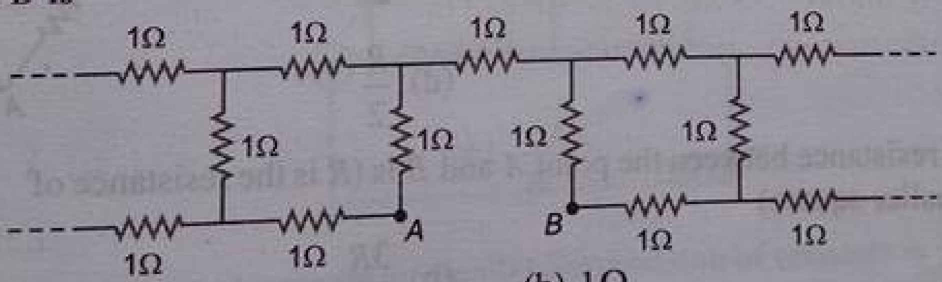
(a) r
(b) $0.5\,r$
(c) $2\,r$
(d) $3\,r$

35. A uniform wire of resistance $18\,\Omega$ is bent in the form of a circle. The effective resistance across the points a and b is



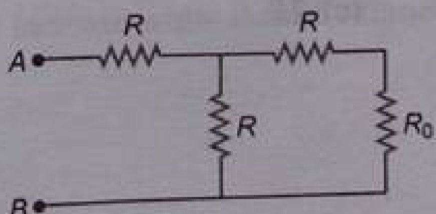
(a) $3\,\Omega$
(b) $2\,\Omega$
(c) $2.5\,\Omega$
(d) $6\,\Omega$

36. Each resistor shown in figure is an infinite network of resistance $1\,\Omega$. The effective resistance in between A and B is



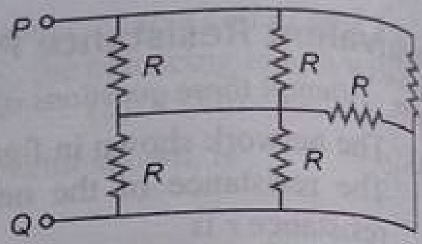
(a) less than $1\,\Omega$
(b) $1\,\Omega$
(c) more than $1\,\Omega$ but less than $3\,\Omega$
(d) $3\,\Omega$

37. In the circuit shown in figure, the total resistance between points A and B is R_0. The value of resistance R is



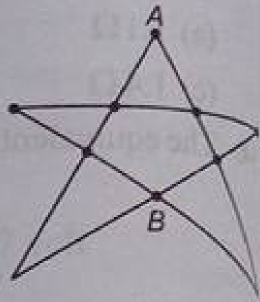
(a) R_0
(b) $\sqrt{3}\,R_0$
(c) $\dfrac{R_0}{2}$
(d) $\dfrac{R_0}{\sqrt{3}}$

38. In the circuit shown in the figure, $R = 55\,\Omega$, the equivalent resistance between the points P and Q is



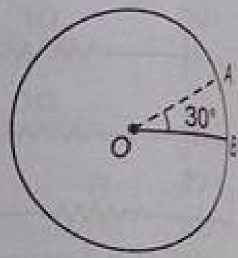
(a) $30\,\Omega$
(b) $35\,\Omega$
(c) $55\,\Omega$
(d) $25\,\Omega$

39. The resistance of all the wires between any two adjacent dots is R. Then equivalent resistance between A and B as shown in the figure is



(a) $(7/3)\,R$
(b) $(7/6)\,R$
(c) $(14/8)\,R$
(d) None of the above

40. A uniform wire of resistance $36\,\Omega$ is bent in the form of a circle. The effective resistance across the points A and B is

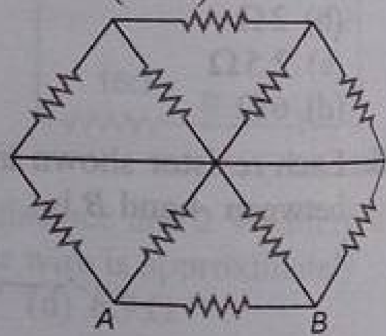


(a) $36\,\Omega$
(b) $18\,\Omega$
(c) $9\,\Omega$
(d) $2.75\,\Omega$

41. A uniform wire of resistance $4\,\Omega$ is bent into the form of a circle of radius r. A specimen of the same wire is connected along the diameter of the circle. What is the equivalent resistance across the ends of this wire?

(a) $\dfrac{4}{(4+\pi)}\,\Omega$ (b) $\dfrac{3}{(3+\pi)}\,\Omega$ (c) $\dfrac{2}{(2+\pi)}\,\Omega$ (d) $\dfrac{1}{(1+\pi)}\,\Omega$

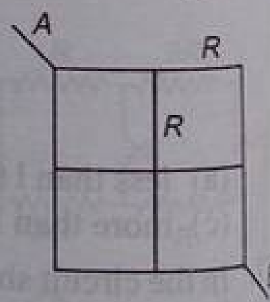
42. In the network shown in figure, each resistance is R. The equivalent resistance between points A and B is



(a) $\dfrac{20}{11}R$ (b) $\dfrac{19}{20}R$

(c) $\dfrac{8}{15}R$ (d) $\dfrac{R}{2}$

43. The equivalent resistance between the point A and B is (R is the resistance of each side of smaller square)



(a) R (b) $\dfrac{3R}{2}$

(c) $2R$ (d) $\dfrac{R}{2}$

JEE Corner

Assertion and Reason

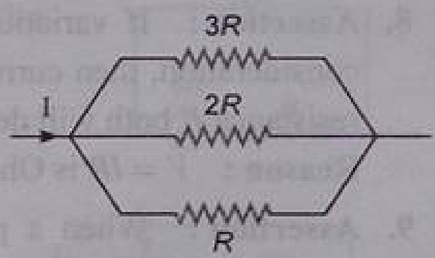
Directions : *Choose the correct option.*

(a) *If both **Assertion** and **Reason** are true and the **Reason** is correct explanation of the **Assertion.***
(b) *If both **Assertion** and **Reason** are true but **Reason** is not the correct explanation of **Assertion.***
(c) *If **Assertion** is true, but the **Reason** is false.*
(d) *If **Assertion** is false but the **Reason** is true.*

1. **Assertion :** If potential difference across two points is zero, current between these two points should be zero.
Reason : Current passing from a resistor

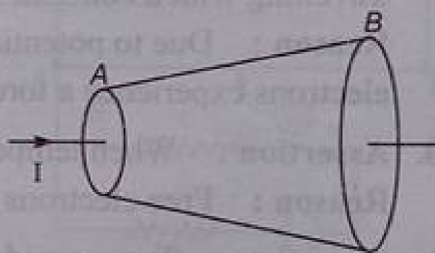
$$I = \frac{V}{R}$$

2. **Assertion :** In the part of the circuit shown in figure, maximum power is produced across R.

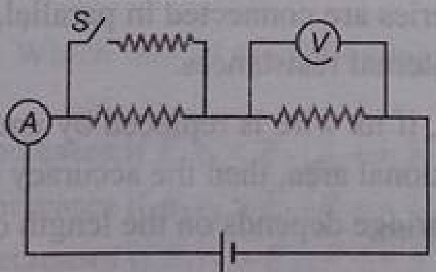


Reason : Power $P = \frac{V^2}{R}$

3. **Assertion :** Current I is flowing through a cylindrical wire of non-uniform cross-section as shown. Section of wire near A will be more heated compared to the section near B.
Reason : Current density near A is more.

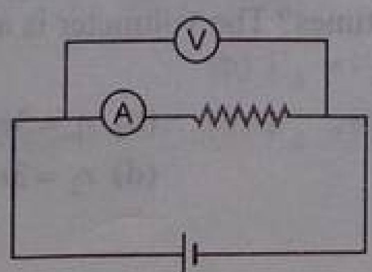


4. **Assertion :** In the circuit shown in figure after closing the switch S reading of ammeter will increase while that of voltmeter will decrease.



Reason : Net resistance decreases as parallel combination of resistors is increased.

5. **Assertion :** In the circuit shown in figure ammeter and voltmeter are non-ideal. When positions of ammeter and voltmeter are changed, reading of ammeter will increase while that of voltmeter will decrease.

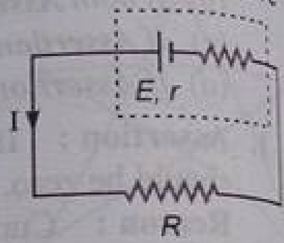


Reason : Resistance of an ideal ammeter is zero while that of an ideal voltmeter is infinite.

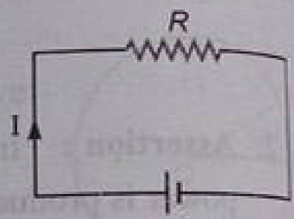
6. **Assertion :** In the part of a circuit shown in figure, given that $V_b > V_a$. The current should flow from b to a.

Reason : Direction of current inside a battery is always from negative terminal to positive terminal.

7. **Assertion :** In the circuit shown in figure R is variable. Value of current I is maximum when $R = r$.



Reason : At $R = r$, maximum power is produced across R.



8. **Assertion :** If variation in resistance due to temperature is taken into consideration, then current in the circuit I and power produced across the resistance P both will decrease with time.

Reason : $V = IR$ is Ohm's law.

9. **Assertion :** When a potential difference is applied across a conductor, free electrons start travelling with a constant speed called drift speed.

Reason : Due to potential difference an electric field is produced inside the conductor, in which electrons experience a force.

10. **Assertion :** When temperature of a conductor is increased its resistance increases.

Reason : Free electrons collide more frequently.

11. **Assertion :** Two non-ideal batteries are connected in parallel with same polarities on same side. The equivalent emf is smaller than either of the two emfs.

Reason : Two non-ideal batteries are connected in parallel, the equivalent internal resistance is smaller than either of the two internal resistances.

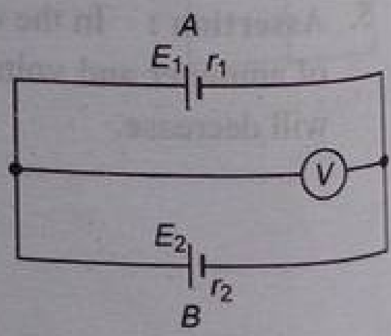
12. **Assertion :** In a meter bridge, if its wire is replaced by another wire having same length, same material but twice the cross sectional area, then the accuracy of measurement decreases.

Reason : Accuracy of meter bridge depends on the length of wire.

Objective Questions (Level 2)

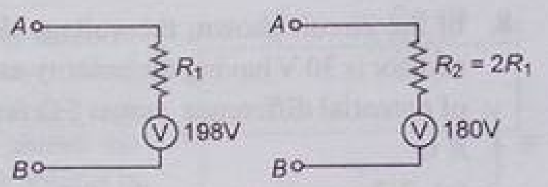
Single Correct Option

1. Two cells A and B of emf 1.3 V and 1.5 V respectively are arranged as shown in figure. The voltmeter reads 1.45 V. Which cell has the higher internal resistance and how many times? The voltmeter is assumed to be ideal



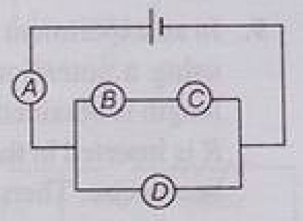
(a) $r_1 = 2r_2$
(b) $r_1 = 3r_2$
(c) $r_2 = 2r_1$
(d) $r_2 = 3r_1$

2. A voltmeter connected in series with a resistance R_1 to a circuit indicates a voltage $V_1 = 198$ V. When a series resistor $R_2 = 2R_1$ is used, the voltmeter indicates a voltage $V_2 = 180$ V. If the resistance of the voltmeter is $R_V = 900\,\Omega$ then, the applied voltage across A and B is



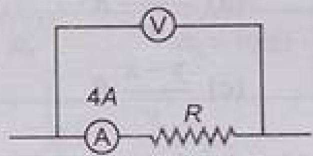
(a) 210 V (b) 200 V (c) 220 V (d) 240 V

3. All bulbs in the circuit shown in figure are identical. Which bulb glows most brightly?



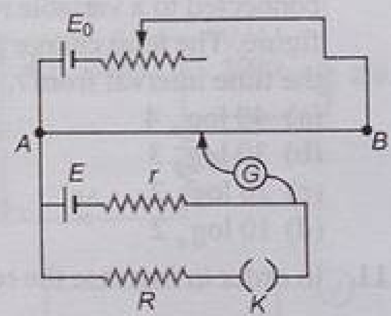
(a) B
(b) A
(c) D
(d) C

4. A student connects an ammeter A and a voltmeter V to measure a resistance R as shown in figure. If the voltmeter reads 20 V and the ammeter reads 4 A, then R is



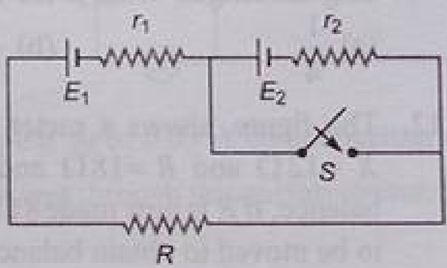
(a) equal to $5\,\Omega$
(b) greater than $5\,\Omega$
(c) less than $5\,\Omega$
(d) greater or less than $5\,\Omega$ depending upon the direction of current

5. The given figure represents an arrangement of potentiometer for the calculation of internal resistance (r) of the unknown battery (E). The balance length is 70.0 cm with the key opened and 60.0 cm with the key closed. R is 132.40 Ω. The internal resistance (r) of the unknown cell will be



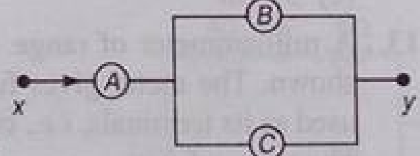
(a) $22.1\,\Omega$
(b) $113.5\,\Omega$
(c) $154.5\,\Omega$
(d) $10\,\Omega$

6. Switch S is closed at time $t = 0$. Which one of the following statements is correct?



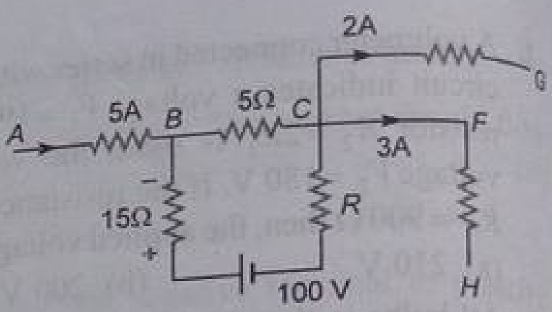
(a) Current in the resistance R increases if $E_1 r_2 < E_2(R + r_1)$
(b) Current in the resistance R increases if $E_1 r_2 > E_2(R + r_1)$
(c) Current in the resistance R decreases if $E_1 r_2 > E_2(R + r_1)$
(d) Current in the resistance R decreases if $E_1 r_2 = E_2(R + r_1)$

7. A, B and C are voltmeters of resistances $R, 1.5R$ and $3R$ respectively. When some potential difference is applied between x and y, the voltmeter readings are V_A, V_B and V_C, then



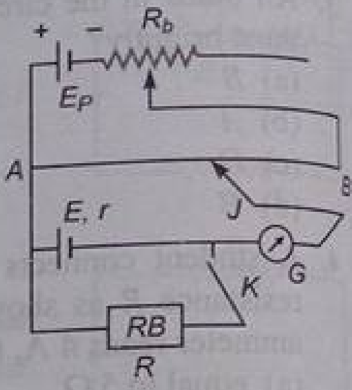
(a) $V_A = V_B = V_C$ (b) $V_A \neq V_B = V_C$
(c) $V_A = V_B \neq V_C$ (d) $V_A + V_B = V_C$

8. In the circuit shown, the voltage drop across the 15 Ω resistor is 30 V having the polarity as indicated. The ratio of potential difference across 5 Ω resistor and resistance R is



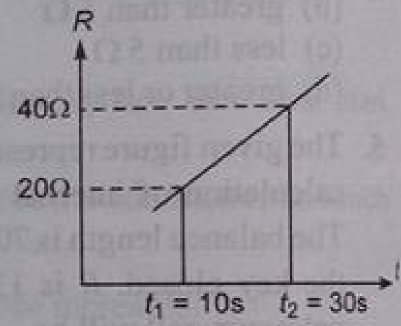
(a) 2/7
(b) 0.4
(c) 5/7
(d) 1

9. In an experiment on the measurement of internal resistance of a cell by using a potentiometer, when the key K is kept open then balancing length is obtained at y metre. When the K is closed and some resistance R is inserted in the resistance box, then the balancing length is found to be x metre. Then the internal resistance is



(a) $\frac{x-y}{y}R$
(b) $\frac{y-x}{x}R$
(c) $\frac{y-x}{y}R$
(d) $\frac{x-y}{x}R$

10. A source of emf $E = 10$ V and having negligible internal resistance is connected to a variable resistance. The resistance varies as shown in figure. The total charge that has passed through the resistor R during the time interval from t_1 to t_2 is

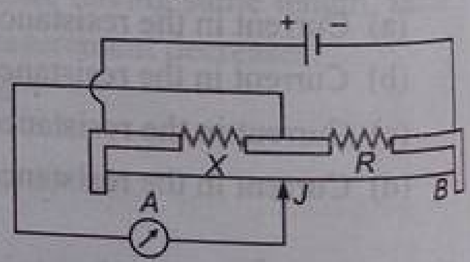


(a) $40 \log_e 4$
(b) $30 \log_e 3$
(c) $20 \log_e 2$
(d) $10 \log_e 2$

11. In order to increase the resistance of a given wire of uniform cross section to four times its value, a fraction of its length is stretched uniformly till the full length of the wire becomes $\frac{3}{2}$ times the original length. What is the value of this fraction ?

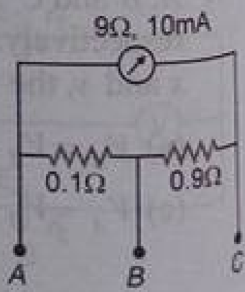
(a) $\frac{1}{4}$
(b) $\frac{1}{8}$
(c) $\frac{1}{16}$
(d) $\frac{1}{6}$

12. The figure, shows a meter bridge circuit, with $AB = 100$ cm, $X = 12\,\Omega$ and $R = 18\,\Omega$ and the jockey J in the position of balance. If R is now made 8 Ω, through what distance will J have to be moved to obtain balance?



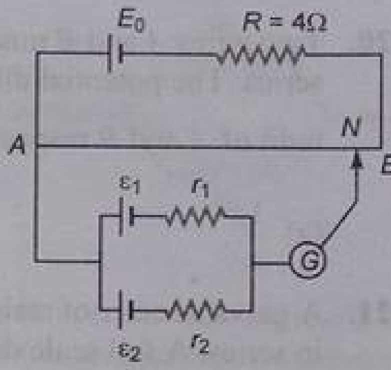
(a) 10 cm
(b) 20 cm
(c) 30 cm
(d) 40 cm

13. A milliammeter of range 10 mA and resistance 9 Ω is joined in a circuit as shown. The meter gives full-scale deflection for current I when A and B are used as its terminals, *i.e.*, current enters at A and leaves at B (C is left isolated). The value of I is



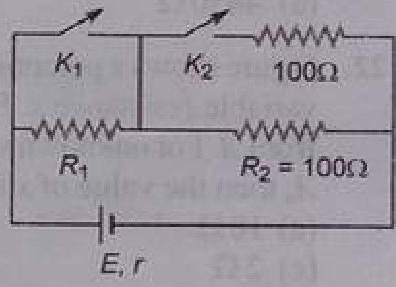
(a) 100 mA
(b) 900 mA
(c) 1 A
(d) 1.1 A

14. A battery of emf $E_0 = 12$ V is connected across a 4 m long uniform wire having resistance 4Ω/m. The cell of small emfs $\varepsilon_1 = 2$ V and $\varepsilon_2 = 4$ V having internal resistance 2Ω and 6Ω respectively are connected as shown in the figure. If galvanometer shows no deflection at the point N, the distance of point N from the point A is equal to



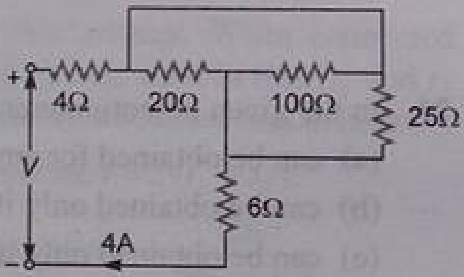
(a) $\frac{1}{6}$ m
(b) $\frac{1}{3}$ m
(c) $\frac{3}{2}$ m
(d) None of these

15. In the circuit shown, when key K_1 is closed, the ammeter reads I_0 whether K_2 is open or closed. But when K_1 is open the ammeter reads $I_0/2$ when K_2 is closed. Assuming that ammeter resistance is much less than R_2, the values of r and R_1 in Ω are



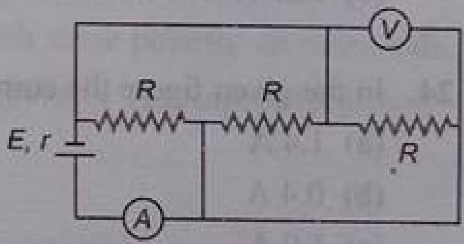
(a) 100, 50
(b) 50, 100
(c) 0, 100
(d) 0, 50

16. In the circuit shown in figure, V must be



(a) 50 V
(b) 80 V
(c) 100 V
(d) 1290 V

17. In the circuit shown in figure ammeter and voltmeter are ideal. If $E = 4$ V, $R = 9\Omega$ and $r = 1\Omega$, then readings of ammeter and voltmeter are

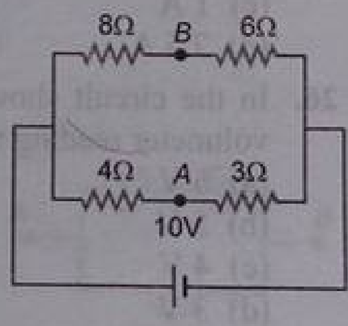


(a) 1 A, 3 V
(b) 2 A, 3 V
(c) 3 A, 4 V
(d) 4 A, 4 V

18. A moving coil galvanometer is converted into an ammeter reading up to 0.03 A by connecting a shunt of resistance $\frac{r}{4}$. What is the maximum current which can be sent through this galvanometer, if no shunt is used. (Here r = resistance of galvanometer)

(a) 0.004 A (b) 0.005 A (c) 0.006 A (d) 0.008 A

19. The potential difference between points A and B is



(a) $\frac{20}{7}$ V
(b) $\frac{40}{7}$ V
(c) $\frac{10}{7}$ V
(d) zero

20. Two wires A and B made of same material and having their lengths in the ratio $6:1$ are connected in series. The potential difference across the wires are 3 V and 2 V respectively. If r_A and r_B are the radii of A and B respectively, then $\frac{r_B}{r_A}$ is

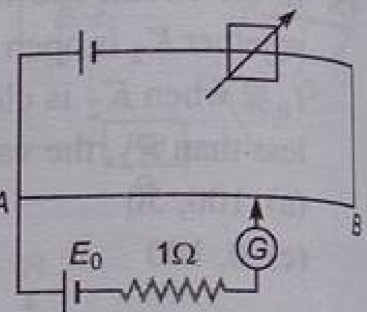
(a) $\frac{1}{4}$ (b) $\frac{1}{2}$ (c) 1 (d) 2

21. A galvanometer of resistance $50\,\Omega$ is connected to a battery of 3 V along with resistance of $2950\,\Omega$ in series. A full scale deflection of 30 divisions is obtained in the galvanometer. In order to reduce this deflection to 20 divisions the resistance in series should be

(a) $4450\,\Omega$ (b) $5050\,\Omega$ (c) $5550\,\Omega$ (d) $6050\,\Omega$

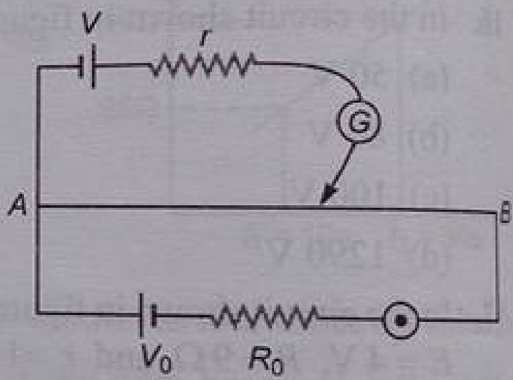
22. Figure shows a potentiometer arrangement with $R_{AB} = 10\,\Omega$ rheostat of variable resistance x. For $x = 0$ null deflection point is found at 20 cm from A. For unknown value of x null deflection point was at 30 cm from A, then the value of x is

(a) $10\,\Omega$ (b) $5\,\Omega$
(c) $2\,\Omega$ (d) $1\,\Omega$



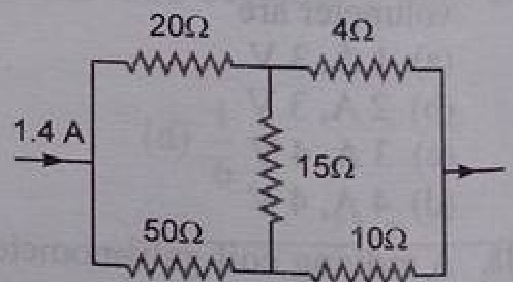
23. In the given potentiometer arrangement, the null point

(a) can be obtained for any value of V
(b) can be obtained only if $V < V_0$
(c) can be obtained only if $V > V_0$
(d) can never be obtained



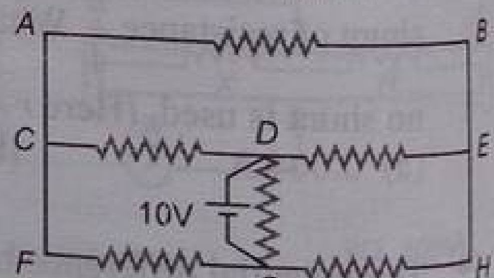
24. In the given figure the current through $4\,\Omega$ resistor is

(a) 1.4 A
(b) 0.4 A
(c) 1.0 A
(d) 0.7 A



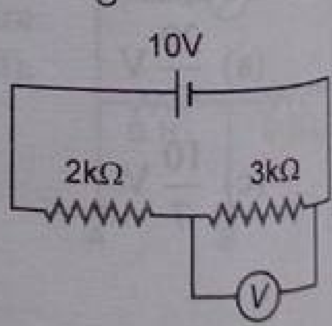
25. All resistances shown in circuit are $2\,\Omega$ each. The current in the resistance between D and E is

(a) 5 A
(b) 2.5 A
(c) 1 A
(d) 7.5 A

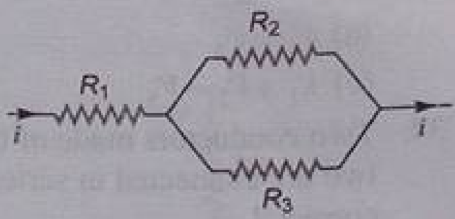


6. In the circuit shown in figure, the resistance of voltmeter is $6\,k\Omega$. The voltmeter reading will be

(a) 6 V
(b) 5 V
(c) 4 V
(d) 3 V



27. For what ratio of R_1, R_2 and R_3 power developed across each resistor is equal?



(a) 1 : 1 : 1
(b) 4 : 4 : 1
(c) 4 : 1 : 1
(d) 1 : 4 : 4

Passage (Q. No. 28 to Q. No. 29)

The length of a potentiometer wire is 600 cm and it carries a current of 40 mA. For a cell of emf 2 V and internal resistance 10 Ω, the null point is found to be at 500 cm. On connecting a voltmeter across the cell, the balancing length is decreased by 10 cm

28. The voltmeter reading will be

(a) 1.96 V (b) 1.8 V (c) 1.64 V (d) 0.96 V

29. The resistance of the voltmeter is

(a) 500 Ω (b) 290 Ω (c) 490 Ω (d) 20 Ω

More than One Correct Options

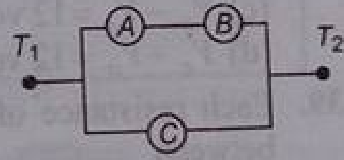
30. Two heaters designed for the same voltage V have different power ratings. When connected individually across a source of voltage V, they produce H amount of heat each in time t_1 and t_2 respectively. When used together across the same source, they produce H amount of heat in time t

(a) If they are in series, $t = t_1 + t_2$
(b) If they are in series, $t = 2(t_1 + t_2)$
(c) If they are in parallel, $t = \dfrac{t_1 t_2}{(t_1 + t_2)}$
(d) If they are in parallel, $t = \dfrac{t_1 t_2}{2(t_1 + t_2)}$

31. Two cells of emf $E_1 = 6$ V and $E_2 = 5$ V are joined in parallel with same polarity on same side, without any external load. If their internal resistances are $r_1 = 2\,\Omega$ and $r_2 = 3\,\Omega$ respectively, then

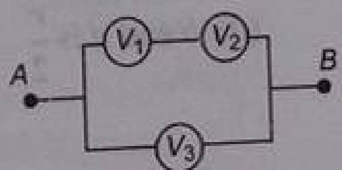
(a) terminal potential difference across any cell is less than 5 V
(b) terminal potential difference across any cell is 5.6 V
(c) current through the cell is 0.2 A
(d) current through the cells is zero if $E_1 = E_2$

32. Three ammeters A, B and C of resistances R_A, R_B and R_C respectively are joined as shown. When some potential difference is applied across the terminals T_1 and T_2 their readings are I_A, I_B and I_C respectively. Then :



(a) $I_A = I_B$
(b) $I_A R_A + I_B R_B = I_C R_C$
(c) $\dfrac{I_A}{I_C} = \dfrac{R_C}{R_A}$
(d) $\dfrac{I_B}{I_C} = \dfrac{R_C}{R_A + R_B}$

33. Three voltmeters all having different resistances, are joined as shown. When some potential difference is applied across A and B, their readings are V_1, V_2 and V_3. Then

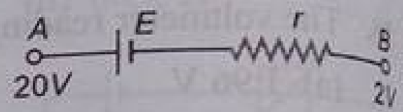


(a) $V_1 = V_2$ (b) $V_1 \neq V_2$

(c) $V_1 + V_2 = V_3$ (d) $V_1 + V_2 > V_3$

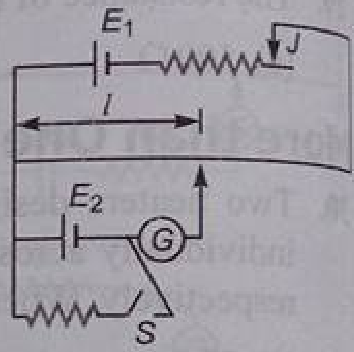
34. Two conductors made of the same material have lengths L and $2L$ but have equal resistances. The two are connected in series in a circuit in which current is flowing. Which of the following is/are correct ?
(a) The potential difference across the two conductors is the same
(b) The drift speed is larger in the conductor of length L
(c) The electric field in the first conductor is twice that in the second
(d) The electric field in the second conductor is twice that in the first

35. In the figure shown



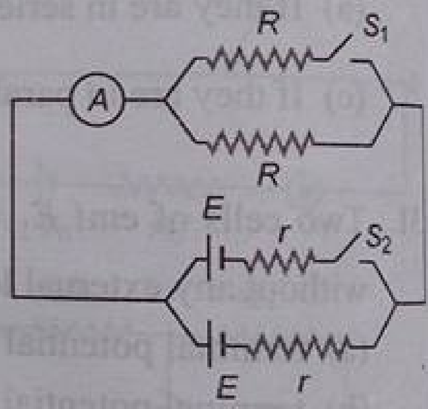
(a) current will flow from A to B
(b) current may flow A to B
(c) current may flow from B to A
(d) the direction of current will depend on E

36. In the potentiometer experiment shown in figure, the null point length is l. Choose the correct options given below.



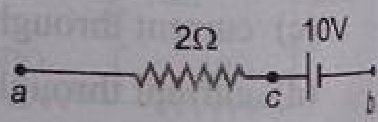
(a) If jockey J is shifted towards right, l will increase
(b) If value of E_1 is increased, l is decreased
(c) If value of E_2 is increased, l is increased
(d) If switch S is closed, l will decrease

37. In the circuit shown in figure, reading of ammeter will



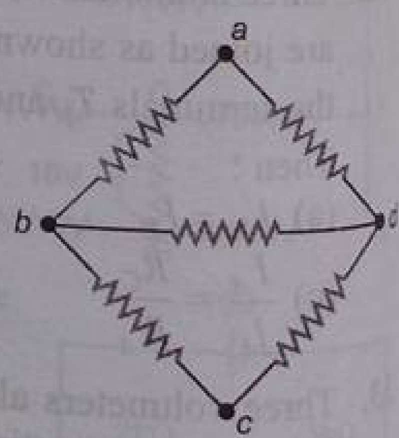
(a) increase if S_1 is closed
(b) decrease if S_1 is closed
(c) increase if S_2 is closed
(d) decrease if S_2 is closed

38. In the circuit shown in figure it is given that $V_b - V_a = 2$ volt. Choose the correct options.



(a) Current in the wire is 6 A
(b) Direction of current is from a to b
(c) $V_a - V_c = 12$ volt
(d) $V_c - V_a = 12$ volt

39. Each resistance of the network shown in figure is r. Net resistance between

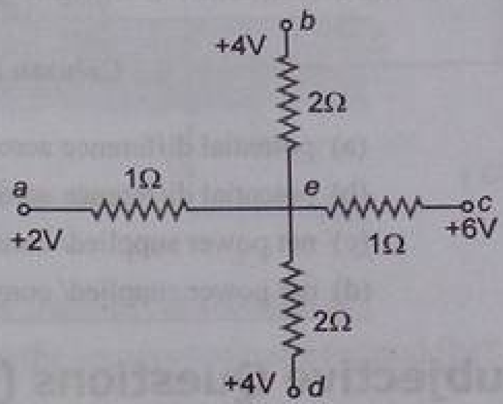


(a) a and b is $\frac{7}{3}r$
(b) a and c is r
(c) b and d is r
(d) b and d is $\frac{r}{2}$

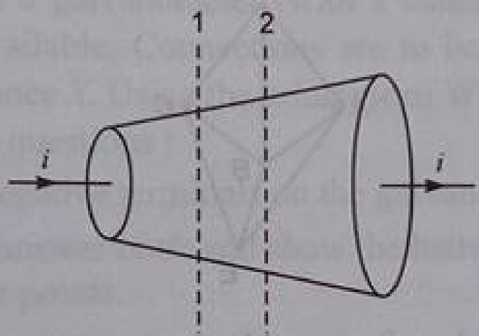
Match the Columns

1. For the circuit shown in figure, match the two columns.

Column I	Column II
(a) current in wire *ae*	(p) 1 A
(b) current is wire *be*	(q) 2 A
(c) current in wire *ce*	(r) 0. 5 A
(d) current in wire *de*	(s) None of these



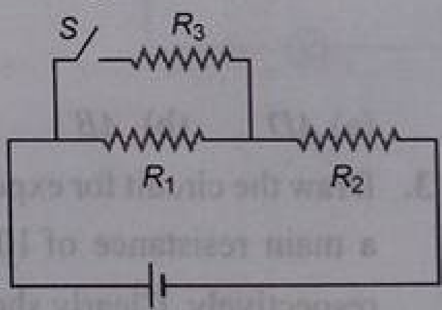
2. Current *i* is flowing through a wire of non-uniform cross section as shown. Match the following two columns.



Column I	Column II
(a) Current density	(p) is more at 1
(b) Electric field	(q) is more at 2
(c) Resistance per unit length	(r) is same at both sections 1 and 2
(d) Potential difference per unit length	(s) data insufficient

3. In the circuit shown in figure, after closing the switch *S*, match the following two columns.

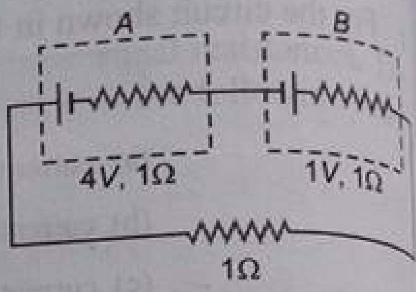
Column I	Column II
(a) current through R_1	(p) will increase
(b) current through R_2	(q) will decrease
(c) potential difference across R_1	(r) will remain same
(d) potential difference across R_2	(s) data insufficient



4. Match the following two columns.

Column I	Column II
(a) Electrical resistance	(p) $[MLT^{-2}A^{2}]$
(b) Electric potential	(q) $[ML^{2}T^{-3}A^{-2}]$
(c) Specific resistance	(r) $[ML^{2}T^{-3}A^{-1}]$
(d) Specific conductance	(s) None of these

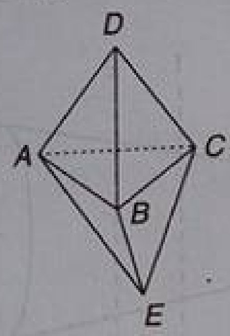
5. In the circuit shown in figure, match the following two columns :



Column I	Column II (In SI units)
(a) potential difference across battery A	(p) zero
(b) potential difference across battery B	(q) 1
(c) net power supplied/ consumed by A	(r) 2
(d) net power supplied/ consumed by B	(s) 3

Subjective Questions (Level 2)

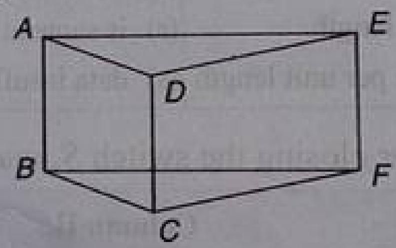
1. Find the equivalent resistance of the triangular bipyramid between the points.



(a) A and C (b) D and E

Assume the resistance of each branch to be R.

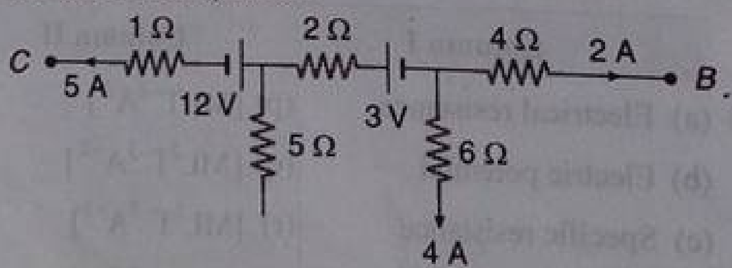
2. Nine wires each of resistance r are connected to make a prism as shown in figure. Find the equivalent resistance of the arrangement across



(a) AD (b) AB

3. Draw the circuit for experimental verification of Ohm's law using a source of variable D.C. voltage, a main resistance of $100\,\Omega$, two galvanometer and two resistance of values $10^6\,\Omega$ and $10^{-3}\,\Omega$ respectively. Clearly show the positions of the voltmeter and the ammeter.

4. The figure shows part of certain circuit, find :

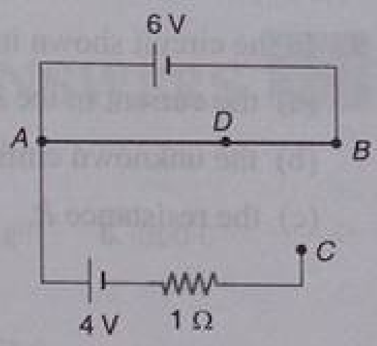


(a) Power dissipated in $5\,\Omega$ resistance.

(b) Potential difference $V_C - V_B$.

(c) Which battery is being charged.

5. A 6 V battery of negligible internal resistance is connected across a uniform wire AB of length 100 cm. The positive terminal of another battery of emf 4 V and internal resistance 1 Ω is joined to the point A as shown in figure. Take the potential at B to be zero.



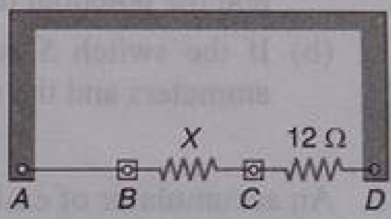
(a) What are the potentials at the points A and C ?

(b) At which point D of the wire AB, the potential is equal to the potential at C ?

(c) If the points C and D are connected by a wire, what will be the current through it ?

(d) If the 4V battery is replaced by 7.5 V battery, what would be the answers of parts (a) and (b)?

6. A thin uniform wire AB of length 1 m, an unknown resistance X and a resistance of 12 Ω are connected by thick conducting strips, as shown in the figure. A battery and a galvanometer (with a sliding jockey connected to it) are also available. Connections are to be made to measure the unknown resistance X. Using the principle of Wheatstone bridge answer the following questions :

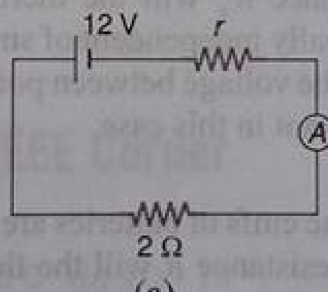


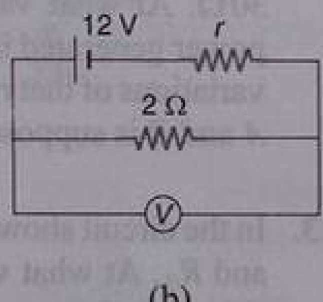
(a) Are there positive and negative terminals on the galvanometer ?

(b) Copy the figure in your answer book and show the battery and the galvanometer (with jockey) connected at appropriate points.

(c) After appropriate connections are made, it is found that no deflection takes place in the galvanometer when the sliding jockey touches the wire at a distance of 60 cm from A. Obtain the value of the resistance X.

7. A galvanometer (coil resistance 99 Ω) is converted into an ammeter using a shunt of 1 Ω and connected as shown in figure (a). The ammeter reads 3 A. The same galvanometer is converted into a voltmeter by connecting a resistance of 101 Ω in series. This voltmeter is connected as shown in figure (b). Its reading is found to be 4/5 of the full scale reading. Find :



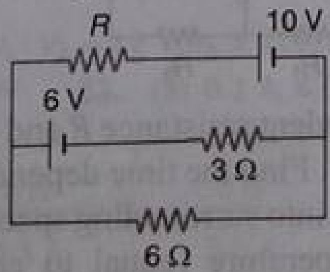


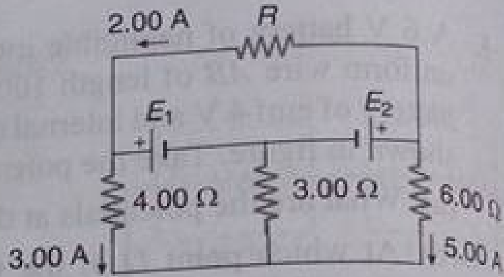
(a) internal resistance r of the cell

(b) range of the ammeter and voltmeter

(c) full scale deflection current of the galvanometer.

8. In a circuit shown in figure if the internal resistances of the sources are negligible then at what value of resistance R will the thermal power generated in it will be the maximum. What is its value ?



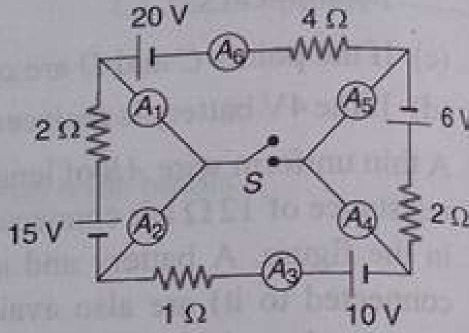


9. In the circuit shown in figure, find :

(a) the current in the 3.00 Ω resistor,

(b) the unknown emfs E_1 and E_2

(c) the resistance R.



10. In the circuit shown, all the ammeters are ideal.

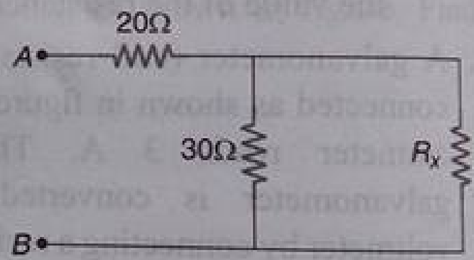
(a) If the switch S is open, find the reading of all ammeters and the potential difference across the switch.

(b) If the switch S is closed, find the current through all ammeters and the switch also.

11. An accumulator of emf 2 V and negligible internal resistance is connected across a uniform wire of length 10 m and resistance 30 Ω. The appropriate terminals of a cell of emf 1.5 V and internal resistance 1 Ω is connected to one end of the wire and the other terminal of the cell is connected through a sensitive galvanometer to a slider on the wire. What is the length of the wire that will be required to produce zero deflection of the galvanometer ? How will the balancing length change ?

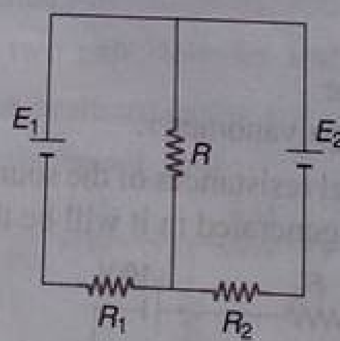
(a) When a coil of resistance 5 Ω is placed in series with the accumulator.

(b) The cell of 1.5 V is shunted with 5 Ω resistor ?



12. A circuit shown in the figure has resistances 20 Ω and 30 Ω. At what value of resistance R_x will the thermal power generated in it be practically independent of small variations of that resistance ? The voltage between points A and B is supposed to be constant in this case.

13. In the circuit shown in figure, the emfs of batteries are E_1 and E_2 which have internal resistances R_1 and R_2. At what value of the resistance R will the thermal power generated in it be the highest ? What it is ?



14. A conductor has a temperature independent resistance R and a total heat capacity C. At the moment $t = 0$ it is connected to a D.C. voltage V. Find the time dependence of the conductor's temperature T assuming the thermal power dissipated into surrounding space to vary as $q = k\,(T - T_0)$, where k is a constant, T_0 is the surrounding temperature (equal to conductor's temperature at the initial moment).

ANSWERS

Introductory Exercise 20.1

1. 1.12 mA **2.** 1.9×10^{-4} m/s **3.** Yes **4.** False **5.** Yes, from left to right **6.** 300 C

Introductory Exercise 20.2

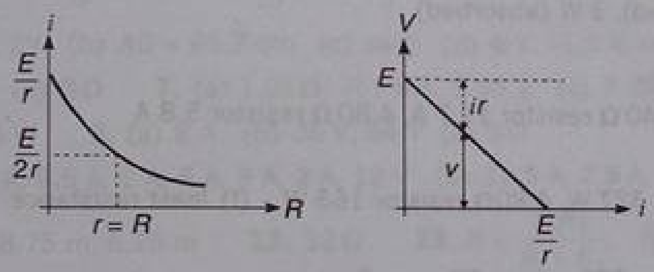
1. 0.18 Ω **2.** (a) 9.9 A (b) 5.88 V (c) 0.60 Ω **3.** $\frac{\rho l}{\pi ab}$ **4.** True **5.** 85° C

Introductory Exercise 20.3

1. 5A, 2.5 A **2.** 0, 2 V, 5 V, 15 V, 3 A from C to B, 7.5 A from D to A.

3. 5 V **4.** $\frac{1}{2}$ A **5.** Zero, 1 A

6.



Introductory Exercise 20.4

1. 3 A, 2 Ω, – 5 V **2.** 36 W, 12 W

Introductory Exercise 20.5

1. 7.5 V, 0.5 Ω **3.** 2 W **4.** By connecting a resistance of 999 Ω in series with galvanometer

5. By connecting 1 Ω resistance in parallel with it **6.** $(n-1)G$ **7.** (a) 320 cm (b) $\frac{3E}{22r}$

AIEEE Corner

Subjective Questions (Level 1)

1. 4.4×10^{18} **2.** 3.9×10^{4} C **3.** (a) 337.5 C (b) 2.1×10^{21}

4. 6.6×10^{15} rps, 1.06 mA **5.** (a) 330 C (b) 41 A **6.** 6.0×10^{-4} m/s

7. 0.735 μ m/s, 431 yr **8.** 10^{20} electrons/s, 16 A **9.** 0.125 Ω **10.** 15 g

11. 954Ω, 0.002 /°C **12.** 0.569 mm **13.** (a) 1.25 V/m (b) 2.84×10^{-8} Ω-m

14. (a) $2d \times 3d, \frac{V}{\rho d}$ (b) $2d \times 3d, \frac{6vd}{\rho}$ **15.** (a) 3.65×10^{-8} Ω-m (b) 172 A (c) 2.58×10^{-3} m/s

16. $R_1 = 18.18\,\Omega, R_2 = 1.82\,\Omega$ **17.** 5 A **18.** 15 A, $\frac{8}{5}$ Ω **19.** $\frac{8}{3}$ Ω, 9 A **20.** $\frac{13}{3}$ A

21. $V_A = 12$ V, $V_B = 9$V, $V_C = 3$V, $V_D = -6$V, $V_A' = 12$ V, $V_B' = 11$V, $V_C' = 9$V, $V_D' = 6$V

22. – 75V, –50V, 125V, 175V, –25V, –200V **23.** (a) 0.1 A, 4.0 V (b) 0.08 A, 4.2 V

24.

Resistance	5 Ω	8 Ω	6 Ω	16 Ω	4 Ω	1 Ω
Current	4 A	0.5 A	3.0 A	0.5 A	1.0 A	4 A
Towards	A	C	C	C	B	E

25. $\frac{20}{3}$ V **26.** (a) (i) 120 V, 80 V (ii) 100 V, 100 V (b) $\frac{1}{60}$ A **27.** 2 V

28. (a) Anticlockwise (b) E_1 (c) Point B

29. (a) 5 V (b) 3 V (c) positive terminal on left side **30.** –10 V

31. (a) zero (b) 5.0 V (c) 5.0 V **32.** (a) 0.20Ω (b) 8.7 V

33. 2.5 V **34.** current in all resistors is zero **35.** $\frac{G^2}{G+S}$ **36.** 20.16Ω **37.** 22.5 V

38. 48 V **39.** 79.995Ω **40.** 1.5Ω **41.** 400 Ω, 3.2 V, 3.238 V **42.** 16 cm from A

43. 12.9Ω **44.** (a) $\frac{ER_V}{R_V + r}$ (b) 4.5×10^{-3} Ω **45.** (a) $I_A\left[1+\frac{R_A}{R+r}\right]$ (b) 0.043Ω

46. 54 W **47.** 82 Ω **48.** 0.6 W, 2 W **49.** +14 W, –1 W

50. (a) $\frac{1}{2}$ A (b) 1 W, 2 W (c) 6 W (supplied), 3 W (absorbed)

51. (a) 24 W (b) 4 W (c) 20 W

52. (a) 0.80 Ω (b) 1.60 Ω resistor 17.5 A, 2.40 Ω resistor 11.7 A, 4.80 Ω resistor 5.8 A
(c) 35.0 A (d) 28.0 V for each
(e) 1.60 Ω resistor 490 W, 2.40 Ω resistor 327 W, 4.80Ω resistor 163 W (f) least resistance

53. (a) 273.8 V (b) 1.6 W

54. (a) $\frac{42}{31}$Ω (b) $\frac{R}{2}$ (c) $\frac{32}{21}$Ω (d) $\frac{25}{6}$Ω (e) $\frac{226}{39}$Ω (f) $\frac{5R}{4}$ (g) $\frac{5}{7}$Ω

55. The new equivalent resistance will become 0.6 times **56.** 23.32 Ω

57. (a) $\frac{5}{8}r$ (b) $\frac{4}{3}r$ (c) r (d) $\frac{r}{4}$ (e) r **58.** (a) $r/2$ (b) $4r/5$

Objective Questions (Level 1)

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

JEE Corner

Assertion and Reason

1. (d)	2. (a,b)	3. (b)	4. (a or b)	5. (b)	6. (c)	7. (d)	8. (c)	9. (d)	10. (a)
11. (d)	12. (d)								

Objective Questions (Level 2)

1.(b)	2.(c)	3.(b)	4.(c)	5.(a)	6.(b)	7.(a)	8.(d)	9.(b)	10.(d)
11.(b)	12.(b)	13.(c)	14.(d)	15.(d)	16.(b)	17.(a)	18.(c)	19.(d)	20.(b)
21.(a)	22.(b)	23.(d)	24.(c)	25.(b)	26.(b)	27.(d)	28.(a)	29.(c)	

More than One Correct Options

32.(a,c) **33.**(b,c,d) **34.**(a,b,d) **35.**(b,c) **36.**(a,b,c) **37.**(b,c,d) **38.**(a,b,c,d) **39.**(a,c) **40.**(a,d) **41.**(b,d)

Match the Columns

1. (a) → q (b) → s (c) → q (d) → s

2. (a) → p (b) → p (c) → p (d) → p

3. (a) → q (b) → p (c) → q (d) → p

4. (a) → q (b) → r (c) → s (d) → s

5. (a) → s (b) → r (c) → s (d) → r

Subjective Questions (Level 2)

1. (a) $\frac{2}{5}R$ (b) $\frac{2}{3}R$ **2.** (a) $\frac{8}{15}r$ (b) $\frac{3}{5}r$ **4.** (a) 605 W (b) 6 V (c) both

5. (a) 6 V, 2V (b) $AD = 66.7$ cm (c) zero (d) 6 V, –1.5 V, no such point D exists.

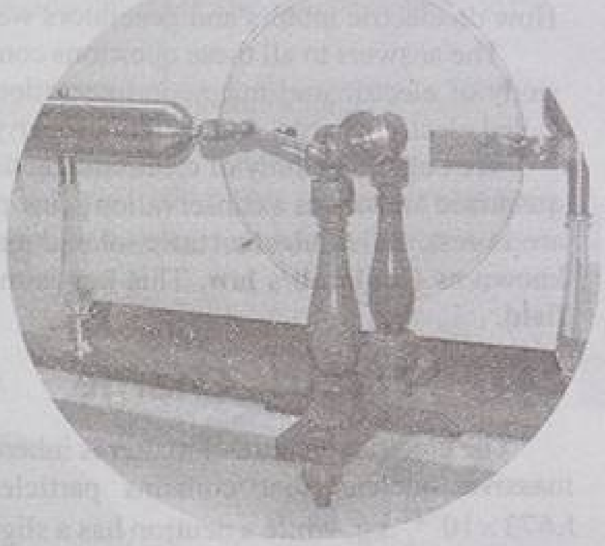
6. (a) No (c) 8Ω **7.** (a) 1.01Ω (b) 5 A, 9.95 V (c) 0.05 A

8. 2Ω, 4.5 W **9.** (a) 8 A (b) 36 V, 54 V (c) 9Ω

10. (a) 9.5 A, 9.5 A, 2 A, 5 A, 5 A, 2 A, 12 V (b) 12.5 A, 2.5 A, 10 A, 7 A, 8 A, 5 A, 15 A

11. 7.5 m, 8.75 m, 6.25 m **12.** 12Ω **13.** $R = \frac{R_1R_2}{R_1 + R_2}$, $P_{max} = \frac{(E_1R_2 + E_2R_1)^2}{4R_1R_2(R_1 + R_2)}$

14. $T = T_0 + (1 - e^{-kt/C})\frac{V^2}{kR}$



21 Electrostatics

Chapter Contents

Solved Examples

Level 1

Example 1 *Five point charges each of value + q are placed on five vertices of a regular hexagon of side 'a' meter. What is the magnitude of the force on a point charge of value – q coulomb placed at the centre of the hexagon?*

Solution

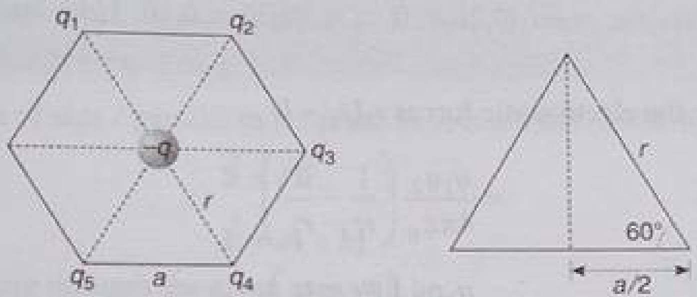


Fig. 21.95

$$\frac{a/2}{r} = \cos 60° = \frac{1}{2}$$

$\therefore$ $$a = r$$

$$q_1 = q_2 = \ldots = q_5 = q$$

Net force on $-q$ is only due to q_3 because forces due to q_1 and due to q_4 are equal and opposite so cancel each other. Similarly, forces due to q_2 and q_5 also cancel each other. Hence, the net force on $-q$ is,

$$F = \frac{1}{4\pi\varepsilon_0} \cdot \frac{(q)(q)}{r^2} \quad \text{(towards } q_3\text{)}$$

or $$F = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q^2}{r^2}$$ **Ans.**

Example 2 *A point charge $q_1 = 9.1\,\mu C$ is held fixed at origin. A second point charge $q_2 = -0.42\,\mu C$ and a mass 3.2×10^{-4} kg is placed on the x-axis, 0.96 m from the origin. The second point charge is released at rest. What is its speed when it is 0.24 m from the origin?*

Solution From conservation of mechanical energy, we have

decrease in gravitational potential energy

= increase in kinetic energy.

or $$\frac{1}{2}mv^2 = U_i - U_f = \frac{q_1 q_2}{4\pi\varepsilon_0}\left(\frac{1}{r_i} - \frac{1}{r_f}\right)$$

$$= \frac{q_1 q_2}{4\pi\varepsilon_0}\left(\frac{r_f - r_i}{r_i r_f}\right)$$

$$\therefore \quad v = \sqrt{\frac{q_1 q_2}{2\pi\varepsilon_0 m}\left(\frac{r_f - r_i}{r_i r_f}\right)}$$

$$= \sqrt{\frac{(9.1\times10^{-6})(-0.42\times10^{-6})\times2\times9\times10^9}{3.2\times10^{-4}}\left(\frac{0.24-0.96}{(0.24)(0.96)}\right)}$$

$$= 26 \text{ m/s}$$ **Ans.**

Example 3 *A point charge $q_1 = -5.8\,\mu C$ is held stationary at the origin. A second point charge $q_2 = +4.3\,\mu C$ moves from the point $(0.26\,m, 0, 0)$ to $(0.38\,m, 0, 0)$. How much work is done by the electric force on q_2?*

Solution Work done by the electrostatic forces $= U_i - U_f$

$$= \frac{q_1 q_2}{4\pi\varepsilon_0}\left(\frac{1}{r_i} - \frac{1}{r_f}\right)$$

$$= \frac{q_1 q_2}{4\pi\varepsilon_0}\left(\frac{r_f - r_i}{r_i r_f}\right)$$

$$= \frac{(-5.8\times10^{-6})(4.3\times10^{-6})(9\times10^9)(0.38-0.26)}{(0.38)(0.26)}$$

$$= -0.272 \text{ J}$$ **Ans.**

Example 4 *A uniformly charged thin ring has radius 10.0 cm and total charge +12.0 nC. An electron is placed on the ring's axis a distance 25.0 cm from the centre of the ring and is constrained to stay on the axis of the ring. The electron is then released from rest.*

(a) describe the subsequent motion of the electron.

(b) find the speed of the electron when it reaches the centre of the ring.

Solution (a) The electron will be attracted towards the centre C of the ring. At C net force is zero, but on reaching C, electron has some kinetic energy and due to inertia it crosses C, but on the other side it is further attracted towards C. Hence, motion of electron is oscillatory about point C.

(b) As the electron approaches C, its speed (hence, kinetic energy) increases due to force of attraction towards the centre C. This increase in kinetic energy is at the cost of electrostatic potential energy. Thus,

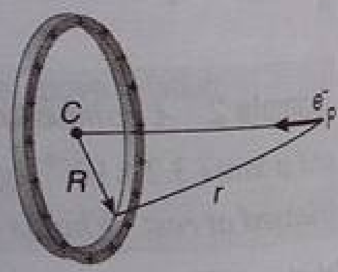


Fig. 21.96

$$\frac{1}{2}mv^2 = U_i - U_f$$

$$= U_p - U_c = (-e)[V_p - V_c] \quad ...(i)$$

Here, V is the potential due to ring.

$$V_p = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r} \quad (q = \text{charge on ring})$$

$$= \frac{(9\times10^9)(12\times10^{-9})}{(\sqrt{(10)^2+(25)^2})\times10^{-2}} = 401 \text{ V}$$

$$V_c = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{R}$$

$$= \frac{(9 \times 10^9)(12 \times 10^{-9})}{10 \times 10^{-2}} = 1080 \text{ V}$$

Substituting the proper values in Eq. (i), we have

$$\frac{1}{2} \times 9.1 \times 100^{-31} \times v^2 = (-1.6 \times 10^{-19})(401 - 1080)$$

$$\therefore \quad v = 15.45 \times 10^6 \text{ m/s}$$

Example 5 *The electric field in a region is given by $\vec{\mathbf{E}} = a\hat{\mathbf{i}} + b\hat{\mathbf{j}}$. Here a and b are constants. Find the net flux passing through a square area of side l parallel to y-z plane.*

Solution A square area of side l parallel to y-z plane in vector form can be written as,

$$\vec{\mathbf{S}} = l^2\hat{\mathbf{i}}$$

Given, $$\vec{\mathbf{E}} = a\hat{\mathbf{i}} + b\hat{\mathbf{j}}$$

$\therefore$ Electric flux passing through the given area will be,

$$\phi_e = \vec{\mathbf{E}} \cdot \vec{\mathbf{s}}$$

$$= (a\hat{\mathbf{i}} + b\hat{\mathbf{j}}) \cdot (l^2\hat{\mathbf{i}})$$

$$= al^2$$

Ans.

Example 6 *Figure shows an imaginary cube of side a. A uniformly charged rod of length a moves towards right at a constant speed v. At t = 0, the right end of the rod just touches the left face of the cube. Plot a graph between electric flux passing through the cube versus time.*

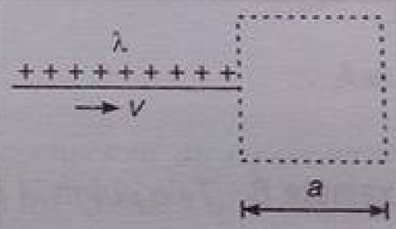


Fig. 21.97

Solution The electric flux, passing through a closed surface depends on the net charge inside the surface. Net charge in this case first increases, reaches a maximum value and finally decreases to zero. The same is the case with the electric flux. The electric flux ϕ_e *versus* time graph is as shown in figure below :

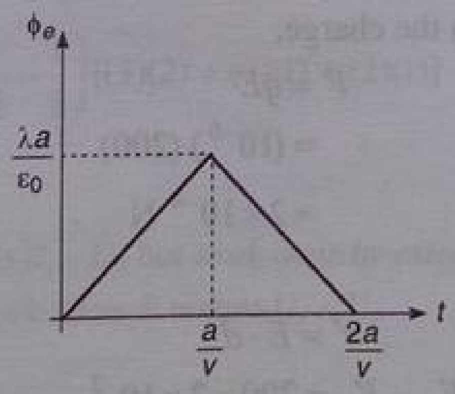


Fig. 21.98

Example 7 *A charged particle of mass $m = 1$ kg and charge $q = 2\,\mu C$ is thrown from a horizontal ground at an angle $\theta = 45°$ with speed 20 m/s. In space a horizontal electric field $E = 2 \times 10^7$ V/m exist. Find the range on horizontal ground of the projectile thrown.*

Solution The path of the particle will be a parabola, but along x-axis also motion of the particle will be accelerated. Time of flight of the projectile is:

$$T = \frac{2u_y}{a_y} = \frac{2u_y}{g}$$

$$= \frac{2 \times 20 \cos 45°}{10} = 2\sqrt{2}\ \text{s}$$

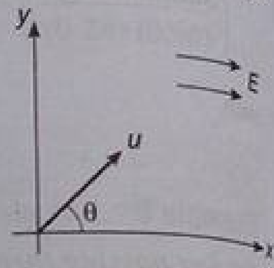


Fig. 21.99

Horizontal range of the particle will be,

$$R = u_x T + \frac{1}{2} a_x T^2$$

Here,

$$a_x = \frac{qE}{m}$$

$$= \frac{(2 \times 10^{-6})(2 \times 10^7)}{1} = 40\ \text{m/s}^2$$

$\therefore$

$$R = (20 \cos 45°)(2\sqrt{2}) + \frac{1}{2}(40)(2\sqrt{2})^2$$

$$= 40 + 160$$

$$= 200\ \text{m}$$ **Ans.**

Example 8 *Two points A and B are 2 cm apart and a uniform electric field E acts along the straight line AB directed from A to B with $E = 200$ N/C. A particle of charge $+10^{-6}$ C is taken from A to B along AB. Calculate*

(a) the force on the charge

(b) the potential difference $V_A - V_B$ and

(c) the work done on the charge by $\vec{\mathbf{E}}$.

Solution (a) Electrostatic force on the charge,

$$F = qE$$

$$= (10^{-6})(200)$$

$$= 2 \times 10^{-4}\ \text{N}$$ **Ans.**

(b) In uniform electric field,

P.D., $$V = E \cdot d$$

or $$V_A - V_B = 200 \times 2 \times 10^{-2}$$

$$= 4\ \text{volt}$$ **Ans.**

(c)

$$W = F \cdot s\cos\theta$$
$$= (2\times10^{-4})(2\times10^{-2})\cos 0^\circ$$
$$= 4\times10^{-6}\ \text{J}$$

Ans.

Example 9 *An alpha particle with kinetic energy 10 MeV is heading towards a stationary tin nucleus of atomic number 50. Calculate the distance of closest approach.*

Solution Due to repulsion by the tin nucleus, the kinetic energy of the α-particle gradually decreses at the expense of electrostatic potential energy.

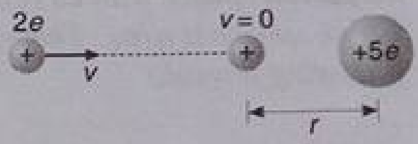


Fig. 21.100

$\therefore$ Decrease in kinetic energy = increase in potential energy

or
$$\frac{1}{2}mv^2 = U_f - U_i$$

or
$$\frac{1}{2}mv^2 = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_1q_2}{r} - 0$$

$\therefore$
$$r = \frac{1}{4\pi\varepsilon_0}\cdot\frac{(2e)(s_0e)}{(\text{KE})}$$

Substituting the values,

$$r = \frac{(9\times10^9)(2\times1.6\times10^{-19})(1.6\times10^{-19}\times50)}{10\times10^6\times1.6\times10^{-19}}$$
$$= 14.4\times10^{-15}\ \text{m}$$

Ans.

Example 10 *Three point charges of 1 C, 2 C and 3 C are placed at the corners of an equilateral triangle of side 1 m. Calculate the work required to move these charges to the corners of a smaller equilateral triangle of side 1.5 m.*

olution Work done $= U_f - U_i$

$$= \frac{1}{4\pi\varepsilon_0}\left(\frac{1}{r_f} - \frac{1}{r_i}\right)[q_3q_2 + q_3q_1 + q_2q_1]$$
$$= 9\times10^9\left(\frac{1}{0.5} - \frac{1}{1}\right)[(3)(2) + (3)(1) + (2)(1)]$$
$$= 99\times10^9\ \text{J}$$

Ans.

ote *Work done by electrostatic forces is $U_i - U_f$ but work done by external forces is $U_f - U_i$. Sometimes in a simple way it is asked, find the work done. It means $U_f - U_i$.*

Level 2

Example 1 *A point charge q is placed on the top of a cone of semi vertex angle θ. Show that the electric flux through the base of the cone is* $\frac{q(1-\cos\theta)}{2\varepsilon_0}$.

HOW TO PROCEED *This problem can be solved by the method of symmetry. Consider a Gaussian surface, a sphere with its centre at the top and radius the slant length of the cone. The flux through the whole sphere is* q/ε_0. *Therefore, the flux through the base of the cone can be calculated by using the following formula.*

$$\phi_e = \left(\frac{S}{S_0}\right)\cdot\frac{q}{\varepsilon_0}$$

Here, S_0 = area of whole sphere

and S = area of sphere below the base of the cone

Solution

Let R = slant length of cone = radius of Gaussian sphere

$\therefore$ S_0 = area of whole sphere = $(4\pi R^2)$

S = area of sphere below the base of the cone

$= 2\pi R^2(1-\cos\theta)$

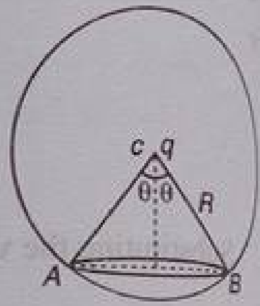


Fig. 21.101

$\therefore$ The desired flux is, $\phi_e = \left(\frac{S}{S_0}\right)\cdot\frac{q}{\varepsilon_0}$

$$= \frac{(2\pi R^2)(1-\cos\theta)}{(4\pi R^2)}\cdot\frac{q}{\varepsilon_0} = \frac{q(1-\cos\theta)}{2\varepsilon_0}$$ **Proved**

Note $S = 2\pi R^2(1-\cos\theta)$ *can be calculated by integration.*

At $\theta = 0°$, $S = 2\pi R^2(1-\cos 0°) = 0$

$\theta = 90°$, $S = 2\pi R^2(1-\cos 90°) = 2\pi R^2$

and $\theta = 180°$, $S = 2\pi R^2(1-\cos 180°) = 4\pi R^2$

Proof :

$$dS = (2\pi r)R\,d\alpha$$

$$= (2\pi R\sin\alpha)R\,d\alpha \qquad as\ r = R\sin\alpha$$

$$= (2\pi R^2)\sin\alpha\,d\alpha$$

$$\therefore \quad S = \int_0^\theta (2\pi R^2)\sin\alpha\,d\alpha$$

$$\therefore \quad S = 2\pi R^2(1-\cos\theta)$$

Students are advised to remember this result.

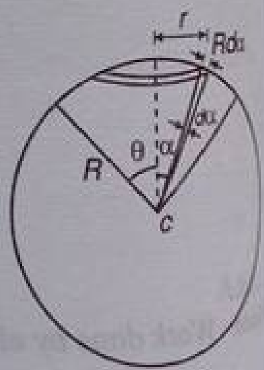


Fig. 21.102

Example 2 *Consider a spherical surface of radius 4 m centred at the origin. Point charges $+q$ and $-2q$ are fixed at points A (2 m, 0, 0) and B (8 m, 0, 0) respectively. Show that every point on the spherical surface is at zero potential.*

Solution Let $P(x, y, z)$ be any point on the sphere. From the property of the sphere,

$$x^2 + y^2 + z^2 = (4^2) = 16 \quad \text{...(i)}$$

Further, $$PA = \sqrt{(x-2)^2 + y^2 + z^2} \quad \text{...(ii)}$$

and $$PB = \sqrt{(x-8)^2 + y^2 + z^2} \quad \text{...(iii)}$$

$$V_P = \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{PA} - \frac{2q}{PB}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{\sqrt{(x-2)^2 + y^2 + z^2}} - \frac{2q}{\sqrt{(x-8)^2 + y^2 + z^2}}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{\sqrt{x^2 + y^2 + z^2 + 4 - 4x}} - \frac{2q}{\sqrt{x^2 + y^2 + z^2 + 64 - 16x}}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{\sqrt{16 + 4 - 4x}} - \frac{2q}{\sqrt{16 + 64 - 16x}}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{\sqrt{20 - 4x}} - \frac{q}{\sqrt{20 - 4x}}\right]$$

$$= 0$$

Proved

Example 3 *The intensity of an electric field depends only on the coordinates x and y as follows.*

$$\vec{\mathbf{E}} = \frac{a(x\,\hat{\mathbf{i}} + y\,\hat{\mathbf{j}})}{x^2 + y^2}$$

where, a is a constant and $\hat{\mathbf{i}}$ and $\hat{\mathbf{j}}$ are the unit vectors of the x and y axes. Find the charge within a sphere of radius R with the centre at the origin.

Solution At any point $P(x, y, z)$ on the sphere a unit vector perpendicular to the sphere radially outwards is,

$$\hat{\mathbf{n}} = \frac{x}{\sqrt{x^2 + y^2 + z^2}}\hat{\mathbf{i}} + \frac{y}{\sqrt{x^2 + y^2 + z^2}}\hat{\mathbf{j}} + \frac{z}{\sqrt{x^2 + y^2 + z^2}}\hat{\mathbf{k}}$$

$$= \frac{x}{R}\hat{\mathbf{i}} + \frac{y}{R}\hat{\mathbf{j}} + \frac{z}{R}\hat{\mathbf{k}}$$

as $$x^2 + y^2 + z^2 = R^2$$

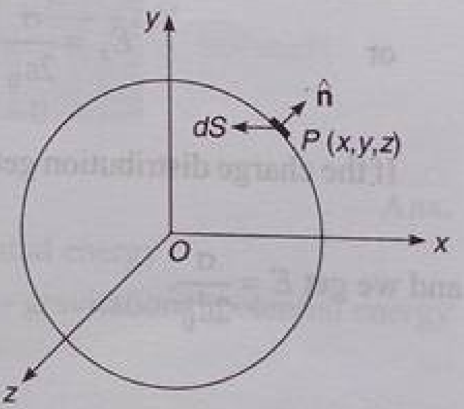


Fig. 21.103

Let us find the electric flux passing through a small area dS at point P on the sphere,

$$d\phi_e = \vec{\mathbf{E}}.\hat{\mathbf{n}}\, dS = \left\{\frac{ax^2}{R(x^2+y^2)} + \frac{ay^2}{R(x^2+y^2)}\right\} dS$$

$$= \left(\frac{a}{R}\right) dS$$

Here, we note that $d\phi_e$ is independent of the co-ordinates x, y and z. Therefore, total flux passing through the sphere

$$\phi_e = \int d\phi_e = \frac{a}{R}\int dS = \left(\frac{a}{R}\right)(4\pi R^2)$$

$$= 4\pi a R$$

From Gauss's law,

$$\phi_e = \frac{q_{in}}{\varepsilon_0} \quad \text{or} \quad (4\pi aR) = \frac{q_{in}}{\varepsilon_0}$$

$\therefore$

$$q_{in} = 4\pi\varepsilon_0 aR$$

Ans.

Example 4 *Find the electric field caused by a disc of radius a with a uniform surface charge density σ (charge per unit area), at a point along the axis of the disc a distance x from its centre.*

Solution We can assume this charge distribution as a collection of concentric rings of charge.

$$dA = (2\pi r)\, dr$$

$$dq = \sigma\, dA = (2\pi\sigma r)\, dr$$

$$dE_x = \frac{1}{4\pi\varepsilon_0}\cdot\frac{(dq)x}{(x^2+r^2)^{3/2}}$$

$$= \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{(2\pi\sigma r\, dr)\, x}{(x^2+r^2)^{3/2}}$$

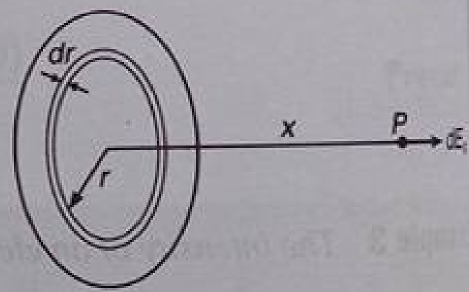


Fig. 21.104

$\therefore$

$$E_x = \int_0^a dE_x = \int_0^a \frac{(2\pi\sigma r\, dr)\, x}{4\pi\varepsilon_0 (x^2+r^2)^{3/2}}$$

$$= \frac{\sigma x}{2\varepsilon_0}\int_0^a \frac{r\, dr}{(x^2+r^2)^{3/2}}$$

or

$$E_x = \frac{\sigma}{2\varepsilon_0}\left[1 - \frac{1}{\sqrt{a^2/x^2+1}}\right]$$

If the charge distribution gets very large, *i.e.*, $a >> x$, the term $\frac{1}{\sqrt{a^2/x^2+1}}$ becomes negligibly small and we get $E = \frac{\sigma}{2\varepsilon_0}$.

Thus, we can say that electric field produced by an infinite plane sheet of charge is independent of the distance from the sheet. Thus, the field is uniform, its direction is everywhere perpendicular to the sheet.

Example 5 *A non-conducting disc of radius a and uniform positive surface charge density σ is placed on the ground with its axis vertical. A particle of mass m and positive charge q is dropped, along the axis of the disc from a height H with zero initial velocity. The particle has $q/m = 4\varepsilon_0 \, g/\sigma$.*

(a) Find the value of H if the particle just reaches the disc.

(b) Sketch the potential energy of the particle as a function of its height and find its equilibrium position.

Solution As we have derived in the theory,

$$V_p = \frac{\sigma}{2\varepsilon_0}[\sqrt{a^2 + H^2} - H]$$

Potential at centre, (O) will be

$$V_o = \frac{\sigma a}{2\varepsilon_0} \qquad (H = 0)$$

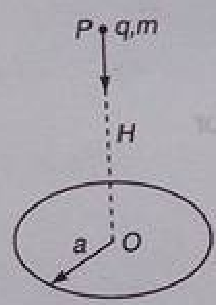


Fig. 21.105

(a) Particle is released from P and it just reaches point O. Therefore, from conservation of mechanical energy

decrease in gravitational potential energy = increase in electrostatic potential energy (Δ KE = 0 because $K_i = K_f = 0$)

$$\therefore \quad mgH = q[V_O - V_P]$$

or

$$gH = \left(\frac{q}{m}\right)\left(\frac{\sigma}{2\varepsilon_0}\right)[a - \sqrt{a^2 + H^2} + H] \qquad \text{...(i)}$$

$$\frac{q}{m} = \frac{4\varepsilon_0 g}{\sigma} \qquad \therefore \quad \frac{q\sigma}{2\varepsilon_0 m} = 2g$$

Substituting in Eq. (i), we get

$$gH = 2g[a + H - \sqrt{a^2 + H^2}]$$

or

$$\frac{H}{2} = (a + H) - \sqrt{a^2 + H^2}$$

or

$$\sqrt{a^2 + H^2} = a + \frac{H}{2} \quad \text{or} \quad a^2 + H^2 = a^2 + \frac{H^2}{4} + aH$$

or

$$\frac{3}{4}H^2 = aH \quad \text{or} \quad H = \frac{4}{3}a \text{ and } H = 0$$

$$\therefore \quad H = (4/3)\,a$$ **Ans.**

(b) Potential energy of the particle at height H = Electrostatic potential energy + gravitational potential energy

$$\therefore \quad U = qV + mgH$$

Here V = Potential at height H

$\therefore$

$$U = \frac{\sigma q}{2\varepsilon_0}[\sqrt{a^2 + H^2} - H] + mgH \quad \text{...(ii)}$$

At equilibrium position, $F = \frac{-dU}{dH} = 0$

Differentiating Eq. (ii) w.r.t. H

$$mg + \frac{\sigma q}{2\varepsilon_0}\left[\left(\frac{1}{2}\right)(2H)\frac{1}{\sqrt{a^2 + H^2}} - 1\right] = 0 \qquad \left[\frac{\sigma q}{2\varepsilon_0} = 2mg\right]$$

or

$$mg + 2mg\left[\frac{H}{\sqrt{a^2 + H^2}} - 1\right] = 0$$

$\therefore$

$$1 + \frac{2H}{\sqrt{a^2 + H^2}} - 2 = 0$$

or

$$\frac{2H}{\sqrt{a^2 + H^2}} = 1$$

or

$$\frac{H^2}{a^2 + H^2} = \frac{1}{4} \quad \text{or} \quad 3H^2 = a^2$$

or

$$H = \frac{a}{\sqrt{3}} \qquad \textbf{Ans.}$$

From Eq. (ii), we can see that,

$$U = 2mga \text{ at } H = 0 \text{ and}$$

$$U = U_{min} = \sqrt{3}\, mga \text{ at } H = \frac{a}{\sqrt{3}}$$

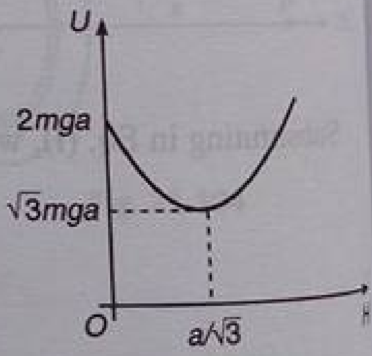


Fig. 21.106

Therefore, U-H graph will be as shown.

Note that at $H = \frac{a}{\sqrt{3}}$, U is minimum.

Therefore, $H = \frac{a}{\sqrt{3}}$ is stable equilibrium position.

Example 6 *Four point charges* $+8\,\mu C$, $-1\,\mu C$, $-1\,\mu C$ *and* $+8\,\mu C$ *are fixed at the points* $-\sqrt{27/2}$ *m*, $-\sqrt{3/2}$ *m*, $+\sqrt{3/2}$ *m and* $+\sqrt{27/2}$ *m respectively on the Y-axis. A particle of mass* 6×10^{-4} *kg and charge* $+0.1\,\mu C$ *moves along the* $-X$ *direction. Its speed at* $x = +\infty$ *is* v_0. *Find the least value of* v_0 *for which the particle will cross the origin. Find also the kinetic energy of the particle at the origin. Assume that space is gravity free.*

Solution In the figure,

$$q = 1\,\mu C = 10^{-6}\,C$$

$$q_0 = +0.1\,\mu C = 10^{-7}\,C$$

$$m = 6\times 10^{-4}\,kg$$

and $$Q = 8\,\mu C = 8\times 10^{-6}\,C$$

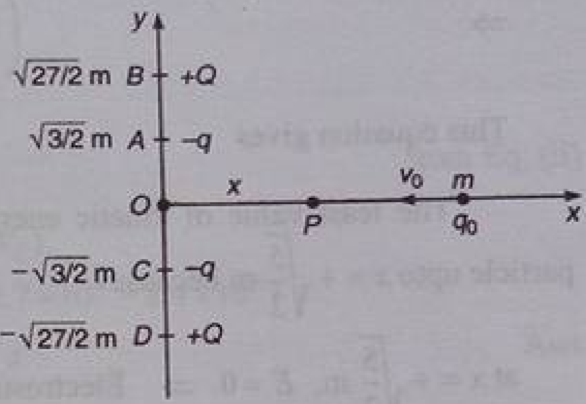


Fig. 21.107

Let P be any point at a distance x from origin O. Then

$$AP = CP = \sqrt{\frac{3}{2} + x^2}$$

$$BP = DP = \sqrt{\frac{27}{2} + x^2}$$

Electric potential at point P will be

$$V = \frac{2KQ}{BP} - \frac{2Kq}{AP}$$

where $$K = \frac{1}{4\pi\varepsilon_0} = 9\times 10^9\ Nm^2/C^2$$

$\therefore$ $$V = 2\times 9\times 10^9\left[\frac{8\times 10^{-6}}{\sqrt{\frac{27}{2}+x^2}} - \frac{10^{-6}}{\sqrt{\frac{3}{2}+x^2}}\right]$$

$$V = 1.8\times 10^4\left[\frac{8}{\sqrt{\frac{27}{2}+x^2}} - \frac{1}{\sqrt{\frac{3}{2}+x^2}}\right] \quad \ldots\text{(i)}$$

$\therefore$ Electric field at P is

$$E = -\frac{dV}{dx} = -1.8\times 10^4\left[(8)\left(-\frac{1}{2}\right)\left(\frac{27}{2}+x^2\right)^{-3/2} - (1)\left(-\frac{1}{2}\right)\left(\frac{3}{2}+x^2\right)^{-3/2}\right](2x)$$

$E = 0$ on X-axis where

$$\frac{8}{\left(\frac{27}{2}+x^2\right)^{3/2}} = \frac{1}{\left(\frac{3}{2}+x^2\right)^{3/2}}$$

$\Rightarrow$ $$\frac{(4)^{3/2}}{\left(\frac{27}{2}+x^2\right)^{3/2}} = \frac{1}{\left(\frac{3}{2}+x^2\right)^{3/2}}$$

$$\Rightarrow \qquad \left(\frac{27}{2}+x^2\right)=4\left(\frac{3}{2}+x^2\right)$$

This equation gives

$$x=\pm\sqrt{\frac{5}{2}}\ \text{m}$$

The least value of kinetic energy of the particle at infinity should be enough to take the particle upto $x=+\sqrt{\frac{5}{2}}$ m because

at $x=+\sqrt{\frac{5}{2}}$ m, $E=0$ $\Rightarrow$ Electrostatic force on charge q_0 is zero or $F_e=0$

for $x>\sqrt{\frac{5}{2}}$ m, E is repulsive (towards positive X-axis)

and for $x<\sqrt{\frac{5}{2}}$ m, E is attractive (towards negative X-axis)

Now, from Eq. (i), potential at $x=\sqrt{\frac{5}{2}}$ m

$$V=1.8\times10^4\left[\frac{8}{\sqrt{\frac{27}{2}+\frac{5}{2}}}-\frac{1}{\sqrt{\frac{3}{2}+\frac{5}{2}}}\right]$$

$$V=2.7\times10^4 \text{ volt}$$

Applying energy conservation at $x=\infty$ and $x=\sqrt{\frac{5}{2}}$ m

$$\frac{1}{2}mv_0^2=q_0V \qquad \text{...(ii)}$$

$$\therefore \qquad v_0=\sqrt{\frac{2q_0V}{m}}$$

Substituting the values

$$v_0=\sqrt{\frac{2\times10^{-7}\times2.7\times10^4}{6\times10^{-4}}}$$

$$v_0=3 \text{ m/s}$$

$\therefore$ Minimum value of v_0 is 3 m/s **Ans.**

From Eq. (i), potential at origin ($x=0$) is

$$V_0=1.8\times10^4\left[\frac{8}{\sqrt{\frac{27}{2}}}-\frac{1}{\sqrt{\frac{3}{2}}}\right]=2.4\times10^4 \text{ V}$$

Let T be the kinetic energy of the particle at origin.

Applying energy conservation at $x = 0$ and at $x = \infty$

$$T + q_0 V_0 = \frac{1}{2} m v_0^2$$

But $\qquad \frac{1}{2} m v_0^2 = q_0 V \qquad$ from Eq. (ii)

$\therefore$

$$T = q_0 (V - V_0)$$

$$T = (10^{-7})(2.7 \times 10^4 - 2.4 \times 10^4)$$

$$T = 3 \times 10^{-4}\ \text{J}$$ **Ans.**

Note *$E = 0$ or F_e on q_0 is zero at $x = 0$ and $x = \pm\sqrt{\frac{5}{2}}$ m. Of these $x = 0$ is stable equilibrium position and $x = \pm\sqrt{\frac{5}{2}}$ m is unstable equilibrium position.*

EXERCISES

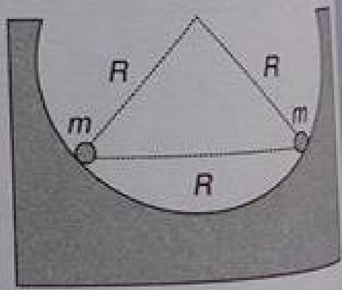
AIEEE Corner

Subjective Questions (Level 1)

Note *You can take approximations in the answers.*

Coulomb's Law

1. A certain charge Q is divided into two parts q and $Q-q$, which are then separated by a certain distance. What must q be in terms of Q to maximise the electrostatic repulsion betweeen the two charges?
2. Two charged particles are placed at a distance 1.0 cm apart. What is the minimum possible magnitude of the electric force acting on each charge?
3. An α-particle is the nucleus of a helium atom. It has a mass $m = 6.64 \times 10^{-27}$ kg and a charge $q = +2e = 3.2 \times 10^{-19}$ C. Compare the force of the electric repulsion between two α-particles with the force of gravitational attraction between them.
4. Two identical conducting spheres, fixed in space, attract each other with an electrostatic force of 0.108 N when separated by 50.0 cm, center-to-center. A thin conducting wire then connects the spheres. When the wire is removed, the spheres repel each other with an electrostatic force of 0.0360 N. What were the initial charges on the spheres?
5. Point charges q_1 and q_2 lie on the x-axis at points $x = -a$ and $x = +a$ respectively.
   (a) How must q_1 and q_2 be related for the net electrostatic force on point charge $+Q$, placed at $x = +a/2$, to be zero?
   (b) With the same point charge $+Q$ now placed at $x = +3a/2$.
6. Two particles (free to move) with charges $+q$ and $+4q$ are a distance L apart. A third charge is placed so that the entire system is in equilibrium.
   (a) Find the location, magnitude and sign of the third charge.
   (b) Show that the equilibrium is unstable.
7. Two identical beads each have a mass m and charge q. When placed in a hemispherical bowl of radius R with frictionless, non-conducting walls, the beads move, and at equilibrium they are a distance R apart (figure). Determine the charge on each bead.

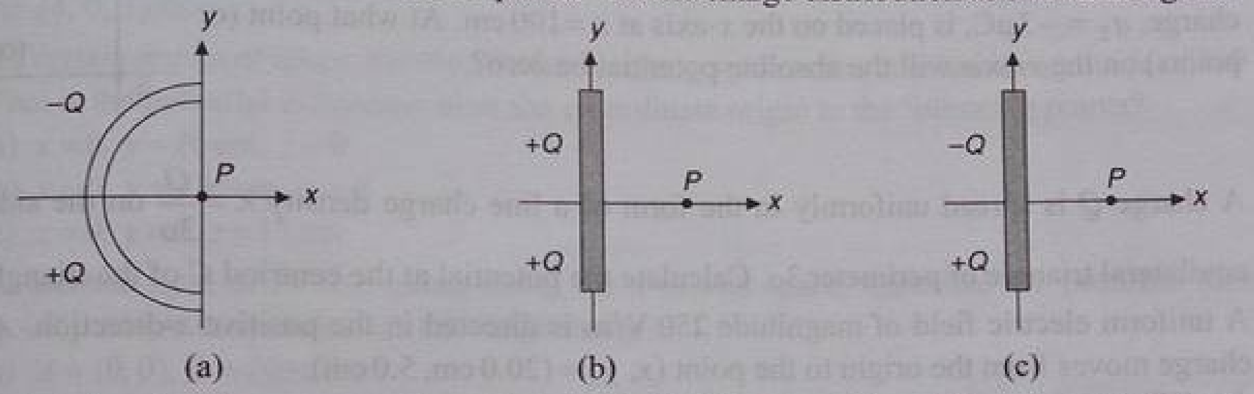


8. Three identical small balls, each of mass 0.1 g, are suspended at one point on silk thread having a length of $l = 20$ cm. What charges should be imparted to the balls for each thread to form an angle of $\alpha = 30°$ with the vertical?

Electric Field

9. Four particles, each having a charge q, are placed on the four vertices of a regular pentagon. The distance of each corner from the centre is a. Find the electric field at the centre of the pentagon.

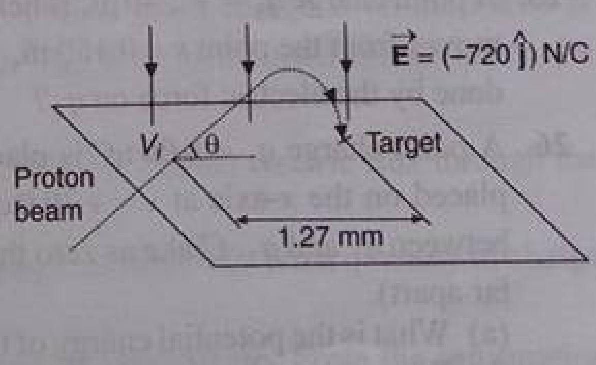
10. Three charges, each equal to q, are placed at the three corners of a square of side a. Find the electric field at fourth corner.
11. A point charge $q = -8.0$ nC is located at the origin. Find the electric field vector at the point $x = 1.2$ m, $y = -1.6$ m.
12. Find the electric field at the centre of a uniformly charged semicircular ring of radius R. Linear charge density is λ.
13. Find the electric field at a point P on the perpendicular bisector of a unifromly charged rod. The length of the rod is L, the charge on it is Q and the distance of P from the centre of the rod is a.
14. Find the direction of electric field at point P for the charge distribution as shown in figure.



15. A clock face has charges $-q, -2q, -3q, \ldots -12q$ fixed at the position of the corresponding numerals on the dial. The clock hands do not disturb the net field due to point charges. At what time does the hour hand point in the direction of the electric field at the centre of the dial.

Electric Forces

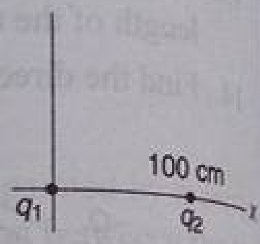
16. An electron with a speed of 5.00×10^8 cm/s enters an electric field of magnitude 1.00×10^3 N/C, travelling along the field lines in the direction that retards its motion.
    (a) How far will the electron travel in the field before stopping momentarily and
    (b) How much time will have elapsed?
    (c) If the region with the electric field is only 8.00 mm long (too short from the electron to stop with in it), what fraction of the electron's initial kinetic energy will be lost in that region?
17. A charged particle of mass $m = 1$ kg and charge $q = 2\ \mu$C is thrown from a horizontal ground at an angle $\theta = 45°$ with the speed 25 m/s. In space a horizontal electric field $E = 2 \times 10^7$ V/m exist. Find the range on horizontal ground of the projectile thrown. Take $g = 10\ \text{m/s}^2$.
18. Protons are projected with an initial speed $v_i = 9.55 \times 10^3$ m/s into a region where a uniform electric field $\vec{\mathbf{E}} = (-720\ \hat{\mathbf{j}})$ N/C is present, as shown in figure. The protons are to hit a target that lies at a horizontal distance of 1.27 mm from the point where the protons are launched. Find :
    (a) the two projection angles θ that result in a hit and
    (b) the total time of flight for each trajectory.



19. At some instant the velocity components of an electron moving between two charged parallel plates are $v_x = 1.5 \times 10^5$ m/s and $v_y = 3.0 \times 10^6$ m/s. Suppose that the electric field between the plates is given by $\vec{\mathbf{E}} = (120\ \text{N/C})\ \hat{\mathbf{j}}$.
(a) What is the acceleration of the electron?
(b) What will be the velocity of the electron after its x-coordinate has changed by 2.0 cm?

Electric potential and Electric potential Energy

20. A point charge $q_1 = +2\mu\text{C}$ is placed at the origin of co-ordinates. A second charge, $q_2 = -3\mu\text{C}$, is placed on the x-axis at $x = 100$ cm. At what point (or points) on the x-axis will the absolute potential be zero?

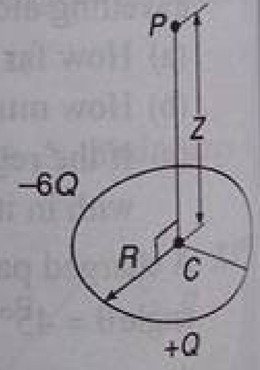


21. A charge Q is spread uniformly in the form of a line charge density $\lambda = \dfrac{Q}{3a}$ on the sides of an equilateral triangle of perimeter $3a$. Calculate the potential at the centriod C of the triangle.

22. A uniform electric field of magnitude 250 V/m is directed in the positive x-direction. A $+12\mu\text{C}$ charge moves from the origin to the point $(x, y) = (20.0\ \text{cm}, 5.0\ \text{cm})$.
(a) What was the change in the potential energy of this charge?
(b) Through what potential difference did the charge move?

23. A small particle has charge $-5.00\ \mu\text{C}$ and mass 2.00×10^{-4} kg. It moves from point A, where the electric potential is $V_A = +200$ V, to point B, where the electric potential is $V_B = +800$ V. The electric force is the only force acting on the particle. The particle has speed 5.00 m/s at point A. What is its speed at point B? Is it moving faster or slower at B than at A? Explain.

24. A plastic rod has been formed into a circle of radius R. It has a positive charge $+Q$ uniformly distributed along one-quarter of its circumference and a negative charge of $-6Q$ uniformly distributed along the rest of the circumference (figure). With $V = 0$ at infinity, what is the electric potential
(a) at the centre C of the circle and
(b) at point P, which is on the central axis of the circle at distance z from the centre?



25. A point charge $q_1 = +2.40\ \mu\text{C}$ is held stationary at the origin. A second point charge $q_2 = -4.30\ \mu\text{C}$ moves from the point $x = 0.150$ m, $y = 0$ to the point $x = 0.250$ m, $y = 0.250$ m. How much work is done by the electric force on q_2?

26. A point charge $q_1 = 4.00$ nC is placed at the origin, and a second point charge $q_2 = -3.00$ nC is placed on the x-axis at $x = +20.0$ cm. A third point charge $q_3 = 2.00$ nC is placed on the x-axis between q_1 and q_2. (Take as zero the potential energy of the three charges when they are infinitely far apart).
(a) What is the potential energy of the system of the three charges if q_3 is placed at $x = +10.0$ cm?
(b) Where should q_3 be placed to make the potential energy of the system equal to zero?

27. Three point charges, which initially are infinitely far apart, are placed at the corners of an equilateral triangle with sides d. Two of the point charges are identical and have charge q. If zero net work is required to place the three charges at the corners of the triangles, what must the value of the third charge be?

Relation between Electric field and potential

28. The electric field in a certain region is given by $\vec{\mathbf{E}} = 5\hat{\mathbf{i}} - 3\hat{\mathbf{j}}$ kV/m. Find the difference in potential $V_B - V_A$. If A is at the origin and point B is at
   (a) (0, 0, 5) m,
   (b) (4, 0, 3) m.

29. In a certain region of space, the electric field is along $+y$ direction and has a magnitude of 400 V/m. What is the potential difference from the co-ordinate origin to the following points?
   (a) $x = 0,\ y = 20$ cm, $z = 0$
   (b) $x = 0,\ y = -30$ cm, $z = 0$
   (c) $x = 0,\ y = 0,\ z = 15$ cm

30. An electric field of 20 N/C exists along the x-axis in space. Calculate the potential difference $V_B - V_A$ where the points A and B are given by :
   (a) $A = (0, 0),\ B = (4\text{m}, 2\text{m})$
   (b) $A = (4\text{m}, 2\text{m}),\ B = (6\text{m}, 5\text{m})$

31. The electric potential existing in space is $V(x, y, z) = A(xy + yz + zx)$.
   (a) Write the dimensional formula of A.
   (b) Find the expression for the electric field.
   (c) If A is 10 SI units, find the magnitude of the electric field at (1m, 1m, 1m)

32. An electric field $\vec{\mathbf{E}} = (20\,\hat{\mathbf{i}} + 30\,\hat{\mathbf{j}})$ N/C exists in the space. If the potential at the origin is taken to be zero, find the potential at (2m, 2m).

33. In a certain region of space, the electric potential is $V(x, y, z) = Axy - Bx^2 + Cy$, where A, B and C are positive constants.
   (a) Calculate the x, y and z components of the electric field.
   (b) At which points is the electric field equal to zero?

Gauss Theorem

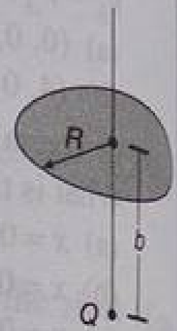
34. A sphere centered at the origin has radius 0.200 m. A $-500\,\mu$C point charge is on the x-axis at $x = 0.300$ m. The net flux through the sphere is 360 N m^2/C. What is the total charge inside the sphere?

35. (a) A closed surface encloses a net charge of $-3.60\,\mu$C. What is the net electric flux through the surface?
   (b) The electric flux through a closed surface is found to be 780 N-m^2/C. What quantity of charge is enclosed by the surface?
   (c) The closed surface in part (b) is a cube with sides of length 2.50 cm. From the information given in part (b), is it possible to tell where within the cube the charge is located? Explain.

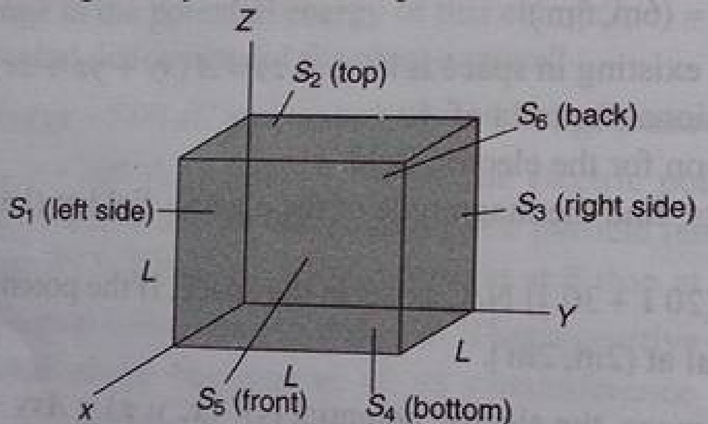
36. The electric field in a region is given by $\vec{E} = \frac{3}{5}E_0\hat{i} + \frac{4}{5}E_0\hat{j}$ with $E_0 = 2.0 \times 10^3$ N/C. Find the flux of this field through a rectangular surface of area $0.2\ m^2$ parallel to the Y-Z plane.

37. The electric field in a region is given by $\vec{E} = \frac{E_0 x}{l}\hat{i}$. Find the charge contained inside a cubical volume bounded by the surfaces $x = 0, x = a, y = 0, y = a, z = 0$ and $z = a$. Take $E_0 = 5 \times 10^3$ N/C, $l = 2$ cm and $a = 1$ cm.

38. A point charge Q is located on the axis of a disc of radius R at a distance b from the plane of the disc (figure). Show that if one-fourth of the electric flux from the charge passes through the disc, then $R = \sqrt{3}\,b$.



39. A cube has sides of length L. It is placed with one corner at the origin as shown in figure. The electric field is uniform and given by $\vec{E} = -B\hat{i} + C\hat{j} - D\hat{k}$, where B, C and D are positive constants.



(a) Find the electric flux through each of the six cube faces S_1, S_2, S_3, S_4, S_5 and S_6.
(b) Find the electric flux through the entire cube.

40. Two point charges q and $-q$ are separated by a distance $2l$. Find the flux of electric field strength vector across the circle of radius R placed with its centre coinciding with the midpoint of line joining the two charges in the perpendicular plane.

41. A point charge q is placed at the origin. Calculate the electric flux through the open hemispherical surface : $(x-a)^2 + y^2 + z^2 = a^2, x \geq a$

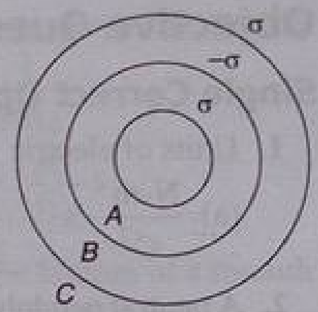
Spherical Surfaces

42. A charge Q is distributed over two concentric hollow spheres of radii r and $R\ (> r)$ such that the surface charge densities are equal. Find the potential at the common centre.

43. Three concentric metallic shells A, B and C of radii a, b and c $(a < b < c)$ have surface charge densities, $\sigma, -\sigma$ and σ respectively.

(a) Find the potentials of three shells A, B and C.

(b) It is found that no work is required to bring a charge q from shell A to shell C then obtain the relation between the radii a, b and c.



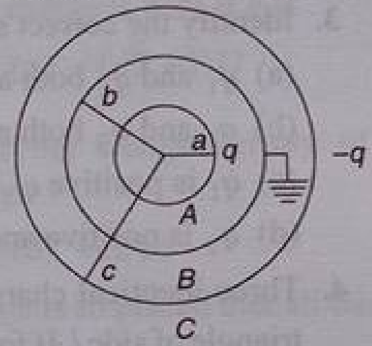
44. A charge Q is placed at the centre of an uncharged, hollow metallic sphere of radius a,

(a) Find the surface charge density on the inner surface and on the outer surface.

(b) If a charge q is put on the sphere, what would be the surface charge densities on the inner and the outer surfaces?

(c) Find the electric field inside the sphere at a distance x from the centre in the situations (a) and (b).

45. Figure shows three concentric thin spherical shells A, B and C of radii a, b and c respectively. The shells A and C are given charges q and $-q$ respectively and the shell B is earthed. Find the charges appearing on the surfaces of B and C.



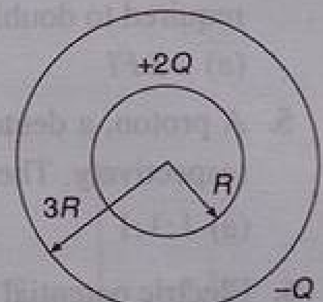
46. A solid sphere of radius R has a charge $+2Q$. A hollow spherical shell of radius $3R$ placed concentric with the first sphere has net charge $-Q$.

(a) Find the electric field between the spheres at a distance r from the centre of the inner sphere. $[R < r < 3R]$

(b) Calculate the potential difference between the spheres.

(c) What would be the final distribution of charges, if a conducting wire joins the spheres?

(d) Instead of (c), if the inner sphere is earthed, what is the charge on it.

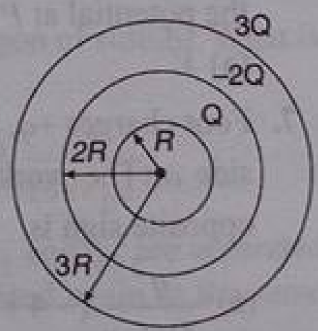


47. Three concentric conducting spherical shells of radii $R, 2R$ and $3R$ carry charges $Q, -2Q$ and $3Q$, respectively.

(a) Find the electric potential at $r = R$ and $r = 3R$, where r is the radial distance from the centre.

(b) Compute the electric field at $r = \frac{5}{2}R$

(c) Compute the total electrostatic energy stored in the system.



The inner shell is now connected to the external one by a conducting wire, passing through a very small hole in the middle shell.

(d) Compute the potential at $r = R$, and the charges on the spheres of radii R and $3R$.

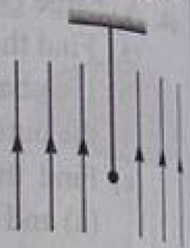
(e) Compute the electric field at $r = \frac{5}{2}R$.

Objective Questions (Level 1)

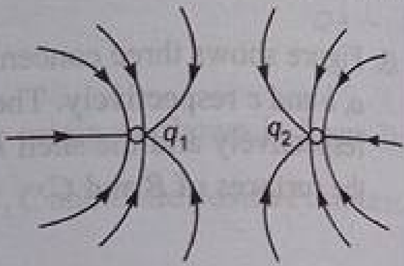
Single Correct Option

1. Units of electric flux are
   (a) $\frac{\text{N-m}^2}{C^2}$ (b) $\frac{\text{N}}{C^2\text{-m}^2}$ (c) volt-m (d) volt-m^3

2. A neutral pendulum oscillates in an uniform electric field as shown in figure. If a positive charge is given to the pendulum then its time period
   (a) will increase
   (b) will decrease
   (c) will remain constant
   (d) will first increase then decrease



3. Identify the correct statement about the charges q_1 and q_2
   (a) q_1 and q_2 both are positive
   (b) q_1 and q_2 both are negative
   (c) q_1 is positive q_2 is negative
   (d) q_2 is positive and q_1 is negative



4. Three identical charges are placed at corners of an equilateral triangle of side l. If force between any two charges is F, the work required to double the dimensions of triangle is
   (a) $-3\,Fl$ (b) $3\,Fl$ (c) $(-3/2)\,Fl$ (d) $(3/2)\,Fl$

5. A proton, a deuteron and an alpha particle are accelerated through potentials of V, 2 V and 4 V respectively. Their velocity will bear a ratio
   (a) 1:1:1 (b) $1:\sqrt{2}:1$ (c) $\sqrt{2}:1:1$ (d) $1:1:\sqrt{2}$

6. Electric potential at a point P, r distance away due to a point charge q at point A is V. If twice of this charge is distributed uniformly on the surface of a hollow sphere of radius $4r$ with centre at point A, the potential at P now is
   (a) V (b) $V/2$ (c) $V/4$ (d) $V/8$

7. Four charges $+q$, $-q$, $+q$ and $-q$ are placed in order on the four consecutive corners of a square of side a. The work done in interchanging the positions of any two neighbouring charges of the opposite sign is
   (a) $\frac{q^2}{4\pi\varepsilon_0 a}(-4+\sqrt{2})$ (b) $\frac{q^2}{4\pi\varepsilon_0 a}(4+2\sqrt{2})$ (c) $\frac{q^2}{4\pi\varepsilon_0 a}(4-2\sqrt{2})$ (d) $\frac{q^2}{4\pi\varepsilon_0 a}(4+\sqrt{2})$

8. Two concentric spheres of radii R and $2R$ are charged. The inner sphere has a charge of 1 μC and the outer sphere has a charge of 2 μC of the same sign. The potential is 9000 V at a distance $3R$ from the common centre. The value of R is
   (a) 1 m (b) 2 m (c) 3 m (d) 4 m

9. A ring of radius R is having two charges q and $2q$ distributed on its two half parts. The electric potential at a point on its axis at a distance of $2\sqrt{2}\,R$ from its centre is $k = \frac{1}{4\pi\varepsilon_0}$

(a) $\frac{3kq}{R}$ (b) $\frac{kq}{3R}$ (c) $\frac{kq}{R}$ (d) $\frac{kq}{\sqrt{3}R}$

10. A particle A having a charge of 2.0×10^{-6} C and a mass of 100 g is fixed at the bottom of a smooth inclined plane of inclination 30°. Where should another particle B having same charge and mass, be placed on the inclined plane so that B may remain in equilibrium?

(a) 8 cm from the bottom (b) 13 cm from the bottom
(c) 21 cm from the bottom (d) 27 cm from the bottom

11. Four positive charges $(2\sqrt{2}-1)Q$ are arranged at the four corner of a square. Another charge q is placed at the centre of the square. Resulting force acting on each corner charge is zero if q is

(a) $-\frac{7Q}{4}$ (b) $-\frac{4Q}{7}$ (c) $-Q$ (d) $-(\sqrt{2}+1)Q$

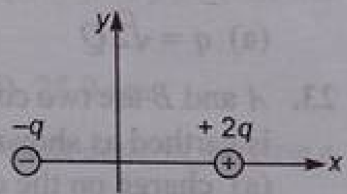
12. A proton is released from rest, 10 cm from a charged sheet carrying charge density of $-2.21 \times 10^{-9}\,\text{C/m}^2$. It will strike the sheet after the time (approximately)

(a) 4 μs (b) 2 μs (c) $2\sqrt{2}$ μs (d) $4\sqrt{2}$ μs

13. Two point charges $+q$ and $-q$ are placed a distance x apart. A third charge is so placed that all the three charges are in equilibrium. Then

(a) unknown charge is $-4q/9$
(b) unknown charge is $-9q/4$
(c) it should be at $(x/3)$ from smaller charge between them
(d) None of the above

14. Charges $2q$ and $-q$ are placed at $(a, 0)$ and $(-a, 0)$ as shown in the figure. The coordinates of the point at which electric field intensity is zero will be $(x, 0)$ where



(a) $-a < x < a$ (b) $x < -a$
(c) $x > -a$ (d) $0 < x < a$

15. Five point charges ($+q$ each) are placed at the five vertices of a regular hexagon of side $2a$. What is the magnitude of the net electric field at the centre of the hexagon?

(a) $\frac{1}{4\pi\varepsilon_0}\frac{q}{a^2}$ (b) $\frac{q}{16\pi\varepsilon_0 a^2}$ (c) $\frac{\sqrt{2}q}{4\pi\varepsilon_0 a^2}$ (d) $\frac{5q}{16\pi\varepsilon_0 a^2}$

16. Two identical small conducting spheres having unequal positive charges q_1 and q_2 are separated by a distance r. If they are now made to touch each other and then separated again to the same distance, the electrostatic force between them in this case will be

(a) less than before (b) same as before (c) more than before (d) zero

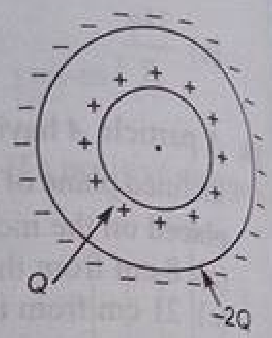
17. Three concentric conducting spherical shells carry charges $+4Q$ on the inner shell $-2Q$ on the middle shell and $+6Q$ on the outer shell. The charge on the inner surface of the outer shell is

(a) 0 (b) $4Q$ (c) $-Q$ (d) $-2Q$

18. 1000 drops of same size are charged to a potential of 1 V each. If they coalesce to form a single drop, its potential would be

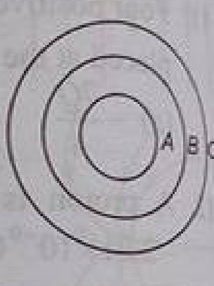
(a) V (b) 10 V (c) 100 V (d) 1000 V

19. Two concentric conducting spheres of radii R and $2R$ are carrying charges Q and $-2Q$ respectively. If the charge on inner sphere is doubled, the potential difference between the two spheres will



(a) become two times
(b) become four times
(c) be halved
(d) remain same

20. Charges $Q, 2Q$ and $-Q$ are given to three concentric conducting spherical shells A, B and C respectively as shown in figure. The ratio of charges on the inner and outer surfaces of shell C will be



(a) $+\frac{3}{4}$ (b) $\frac{-3}{4}$

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

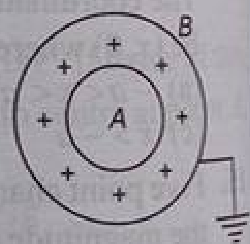
21. The electric field in a region of space is given by $\vec{\mathbf{E}} = 5\hat{\mathbf{i}} + 2\hat{\mathbf{j}}$ N/C. The flux of $\vec{\mathbf{E}}$ due to this field through an area $1\,\text{m}^2$ lying in the y-z plane, in SI units, is

(a) 5 (b) 10 (c) 2 (d) $5\sqrt{29}$

22. A charge Q is placed at each of the two opposite corners of a square. A charge q is placed at each of the other two corners. If the resultant force on each charge q is zero, then

(a) $q = \sqrt{2}Q$ (b) $q = -\sqrt{2}Q$ (c) $q = 2\sqrt{2}Q$ (d) $q = -2\sqrt{2}Q$

23. A and B are two concentric spherical shells. If A is given a charge $+q$ while B is earthed as shown in figure, then



(a) charge on the outer surface of shell B is zero
(b) the charge on B is equal and opposite to that of A
(c) the field inside A and outside B is zero
(d) All of the above

24. A solid sphere of radius R has charge 'q' uniformly distributed over its volume. The distance from its surface at which the electrostatic potential is equal to half of the potential at the centre is

(a) R (b) $2R$ (c) $\frac{R}{3}$ (d) $\frac{R}{2}$

25. Four dipoles each of magnitudes of charges $\pm e$ are placed inside a sphere. The total flux of $\vec{E}$ coming out of the sphere is

(a) zero (b) $\frac{4e}{\varepsilon_0}$ (c) $\frac{8e}{\varepsilon_0}$ (d) None of these

26. A pendulum bob of mass m carrying a charge q is at rest with its string making an angle θ with the vertical in a uniform horizontal electric field E. The tension in the string is

(a) $\frac{mg}{\sin\theta}$ (b) mg (c) $\frac{qE}{\sin\theta}$ (d) $\frac{qE}{\cos\theta}$

27. Two isolated, charged conducting spheres of radii a and b produce the same electric field near their surfaces. The ratio of electric potentials on their surfaces is

(a) $\frac{a}{b}$ (b) $\frac{b}{a}$ (c) $\frac{a^2}{b^2}$ (d) $\frac{b^2}{a^2}$

28. Two point charges $+q$ and $-q$ are held fixed at $(-a, 0)$ and $(a, 0)$ respectively of a x-y coordinate system, then

(a) the electric field $\vec{\mathbf{E}}$ at all points on the x-axis has the same direction
(b) $\vec{\mathbf{E}}$ at all points on the y-axis is along $\hat{\mathbf{i}}$
(c) positive work is done in bringing a test charge from infinity to the origin
(d) All of the above

29. A conducting shell S_1 having a charge Q is surrounded by an uncharged concentric conducting spherical shell S_2. Let the potential difference between S_1 and that S_2 be V. If the shell S_2 is now given a charge $-3Q$, the new potential difference between the same two shells is

(a) V (b) $2V$ (c) $4V$ (d) $-2V$

30. At a certain distance from a point charge, the field intensity is 500 V/m and the potential is -3000 V. The distance to the charge and the magnitude of the charge respectively are

(a) 6 m and 6 μC (b) 4 m and 2 μC (c) 6 m and 4 μC (d) 6 m and 2 μC

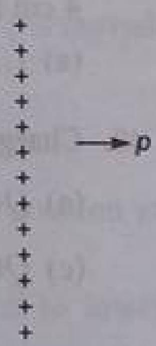
31. Two point charges q_1 and q_2 are placed at a distance of 50 cm from each other in air, and interact with a certain force. The same charges are now put in oil whose relative permitivity is 5. If the interacting force between them is still the same, their separation now is

(a) 16.6 m (b) 22.3 m (c) 28.4 m (d) 25.0 cm

32. An infinite line of charge λ per unit length is placed along the y-axis. The work done in moving a charge q from $A(a, 0)$ to $B(2a, 0)$ is

(a) $\frac{q\lambda}{2\pi\varepsilon_0}\ln 2$ (b) $\frac{q\lambda}{2\pi\varepsilon_0}\ln\left(\frac{1}{2}\right)$ (c) $\frac{q\lambda}{4\pi\varepsilon_0}\ln\sqrt{2}$ (d) $\frac{q\lambda}{4\pi\varepsilon_0}\ln 2$

33. An electric dipole is placed perpendicular to an infinite line of charge at some distance as shown in figure. Identify the correct statement.



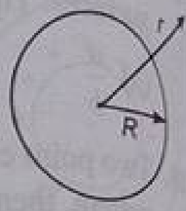
(a) The dipole is attracted towards the line charge
(b) The dipole is repelled away from the line charge
(c) The dipole does not experience a force
(d) The dipole experiences a force as well as a torque

34. An electrical charge 2×10^{-8} C is placed at the point (1, 2, 4) m. At the point (4, 2, 0) m, the electric

(a) potential will be 36 V

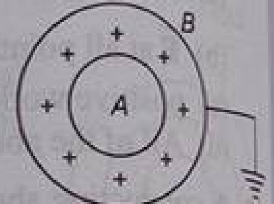
(b) field will be along y-axis
(c) field will increase if the space between the points is filled with a dielectric
(d) All of the above

35. If the potential at the centre of a uniformly charged hollow sphere of radius R is V then electric field at a distance r from the centre of sphere will be $(r > R)$



(a) $\frac{VR}{r^2}$ (b) $\frac{Vr}{R^2}$
(c) $\frac{VR}{r}$ (d) $\frac{VR}{R^2+r^2}$

36. A and B are two concentric spheres. If A is given a charge Q while B is earthed as shown in figure,



(a) the charge density of A and B are same
(b) the field inside and outside A is zero
(c) the field between A and B is not zero
(d) the field inside and outside B is zero

37. There is an electric field E in x-direction. If the work done on moving a charge of 0.2 C through a distance of 2 m along a line making an angle 60° with x-axis is 4 J, then what is the value of E?

(a) $\sqrt{3}$ N/C (b) 4 N/C (c) 5 N/C (d) 20 N/C

38. Two thin wire rings each having radius R are placed at a distance d apart with their axes coinciding. The charges on the two rings are $+Q$ and $-Q$. The potential difference between the centres of the two rings is

(a) zero (b) $\frac{Q}{4\pi\varepsilon_0}\left[\frac{1}{R}-\frac{1}{\sqrt{R^2+d^2}}\right]$
(c) $\frac{Q}{4\pi\varepsilon_0 d^2}$ (d) $\frac{Q}{2\pi\varepsilon_0}\left[\frac{1}{R}-\frac{1}{\sqrt{R^2+d^2}}\right]$

39. The electric field at a distance 2 cm from the centre of a hollow spherical conducting shell of radius 4 cm having a charge of 2×10^{-3} C on its surface is

(a) 1.1×10^{10} V/m (b) 4.5×10^{-10} V/m (c) 4.5×10^{10} V/m (d) zero

40. Charge Q is given a displacement $\vec{\mathbf{r}} = a\hat{\mathbf{i}} + b\hat{\mathbf{j}}$ in an electric field $\vec{\mathbf{E}} = E_1\hat{\mathbf{i}} + E_2\hat{\mathbf{j}}$. The work done is

(a) $Q(E_1 a + E_2 b)$ (b) $Q\sqrt{(E_1 a)^2 + (E_2 b)^2}$
(c) $Q(E_1 + E_2)\sqrt{a^2+b^2}$ (d) $Q\sqrt{E_1^2+E_2^2}\sqrt{a^2+b^2}$

JEE Corner

Assertion and Reason

Directions : *Choose the correct option.*

(a) *If both* ***Assertion*** *and* ***Reason*** *are true and the* ***Reason*** *is correct explanation of the* ***Assertion.***
(b) *If both* ***Assertion*** *and* ***Reason*** *are true but* ***Reason*** *is not the correct explanation of* ***Assertion.***
(c) *If* ***Assertion*** *is true, but the* ***Reason*** *is false.*
(d) *If* ***Assertion*** *is false but the* ***Reason*** *is true.*

1. **Assertion :** An independent negative charge moves itself from point A to point B. Then potential at A should be less than potential at B.

Reason : While moving from A to B kinetic energy of electron will increase.

2. **Assertion :** When two unlike charges are brought nearer, their electrostatic potential energy decreases.

Reason : All conservative forces act in the direction of decreasing potential energy.

3. **Assertion :** At a point electric potential is decreasing along x-axis at a rate of 10 V/m. Therefore x-component of electric field at this point should be 10 V/m along x-axis.

Reason : Magnitude of $E_x = \frac{dV}{dx}$

4. **Assertion :** Electric potential on the surface of a charged sphere of radius R is V. Then electric field at a distance $r = \frac{R}{2}$ from centre is $\frac{V}{2R}$. Charge is distributed uniformly over the volume.

Reason : From centre to surface, electric field varies linearly with r. Here, r is distance from centre.

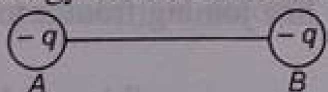
5. **Assertion :** Gauss theorem can be applied only for a closed surface.

Reason : Electric flux can be obtained passing from an open surface also.

6. **Assertion :** In the electric field $\vec{\mathbf{E}} = (4\hat{\mathbf{i}} + 4\hat{\mathbf{j}})$ N/C, electric potential at $A(4m, 0)$ is more than the electric potential at $B(0, 4m)$.

Reason : Electric lines of forces always travel from higher potential to lower potential.

7. **Assertion :** Two charges $-q$ each are fixed at points A and B. When a third charge $-q$ is moved from A to B, electrical potential energy first decreases than increases.



Reason : Along the line joining A and B, the third charge is in stable equilibrium position at centre.

8. **Assertion :** A small electric dipole is moved translationally from higher potential to lower potential in uniform electric field. Work done by electric field is positive.

Reason : When a positive charge is moved from higher potential to lower potential, work done by electric field is positive.

9. **Assertion :** In case of charged spherical shells, E-r graph is discontinuous while V-r graph is continuous.

Reason : According to Gauss theorem the charge inside a closed surface can only produce electric field at some point.

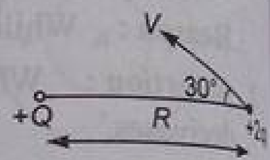
10. **Assertion :** If we see along the axis of a charged ring, the magnitude of electric field is minimum at centre and magnitude of electric potential is maximum.

Reason : Electric field is a vector quantity while electric potential is scalar.

Objective Questions (Level 2)

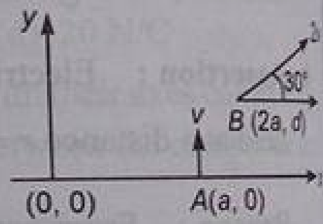
Single Correct Option

1. In the diagram shown, the charge $+Q$ is fixed. Another charge $+2q$ and mass M is projected from a distance R from the fixed charge. Minimum separation between the two charges if the velocity becomes $\frac{1}{\sqrt{3}}$ times of the projected velocity, at this moment is (Assume gravity to be absent)



(a) $\frac{\sqrt{3}}{2}R$ (b) $\frac{1}{\sqrt{3}}R$ (c) $\frac{1}{2}R$ (d) None of these

2. A uniform electric field of strength $\vec{\mathbf{E}}$ exists in a region. An electron enters a point A with velocity v as shown. It moves through the electric field and reaches at point B. Velocity of particle at B is $2v$ at 30° with x-axis. Then



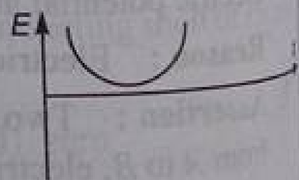
(a) electric field $\vec{\mathbf{E}} = -\frac{3mv^2}{2ea}\hat{\mathbf{i}}$

(b) rate of work done by electric field at B is $\frac{3mv^3}{2ea}$

(c) Both (a) and (b) are correct

(d) Both (a) and (b) are wrong

3. Two point charges a and b whose magnitudes are same positioned at a certain distance along the positive x-axis from each other. a is at origin. Graph is drawn between electrical field strength and distance x from a. E is taken positive if it is along the line joining from a to b. From the graph it can be decided that



(a) a is positive, b is negative (b) a and b both are positive

(c) a and b both are negative (d) a is negative, b is positive

Note *Graph is drawn only between a and b.*

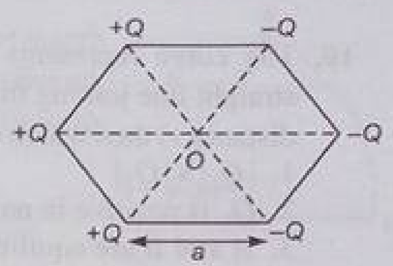
4. Six charges are placed at the vertices of a rectangular hexagon as shown in the figure. The electric field on the line passing through point O and perpendicular to the plane of the figure as a function of distance x from point O is $(x >> a)$

(a) 0

(b) $\dfrac{Qa}{\pi\varepsilon_0 x^3}$

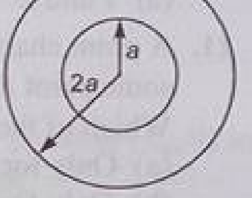
(c) $\dfrac{2Qa}{\pi\varepsilon_0 x^3}$

(d) $\dfrac{\sqrt{3}Qa}{\pi\varepsilon_0 x^3}$



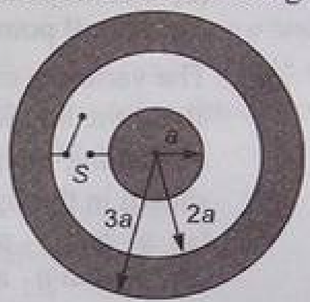
5. If the electric potential of the inner shell is 10 V and that of the outer shell is 5 V, then the potential at the centre will be

(a) 10 V
(b) 5 V
(c) 15 V
(d) zero



6. A solid conducting sphere of radius a having a charge q is surrounded by a concentric conducting spherical shell of inner radius $2a$ and outer radius $3a$ as shown in figure.

Find the amount of heat produced when switch is closed $k = \dfrac{1}{4\pi\varepsilon_0}$;



(a) $\dfrac{kq^2}{2a}$

(b) $\dfrac{kq^2}{3a}$

(c) $\dfrac{kq^2}{4a}$

(d) $\dfrac{kq^2}{6a}$

7. There are four concentric shells A, B, C and D of radii a, $2a$, $3a$ and $4a$ respectively. Shells B and D are given charges $+q$ and $-q$ respectively. Shell C is now earthed. The potential difference $V_A - V_C$ is $k = \dfrac{1}{4\pi\varepsilon_0}$

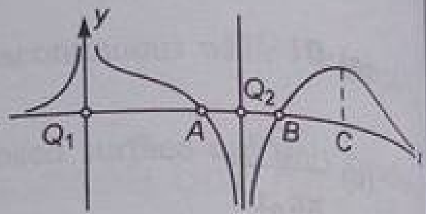
(a) $\dfrac{kq}{2a}$ (b) $\dfrac{kq}{3a}$ (c) $\dfrac{kq}{4a}$ (d) $\dfrac{kq}{6a}$

8. Potential difference between centre and surface of the sphere of radius R and uniform volume charge density ρ within it will be

(a) $\dfrac{\rho R^2}{6\varepsilon_0}$ (b) $\dfrac{\rho R^2}{4\varepsilon_0}$ (c) $\dfrac{\rho R^2}{3\varepsilon_0}$ (d) $\dfrac{\rho R^2}{2\varepsilon_0}$

9. A positively charged disc is placed on a horizontal plane. A charged particle is released from a certain height on its axis. The particle just reaches the centre of the disc. Select the correct alternative.

(a) Particle has negative charge on it
(b) Total potential energy (gravitational + electrostatic) of the particle first increases then decreases
(c) Total potential energy of the particle first decreases then increases
(d) Total potential energy of the particle continuously decreases



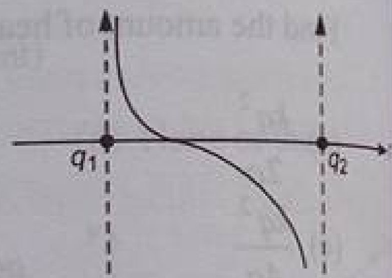
10. The curve represents the distribution of potential along the straight line joining the two charges Q_1 and Q_2 (separated by a distance r) then which of the following statements are correct ?

1. $|Q_1| > |Q_2|$
2. Q_1 is positive in nature
3. A and B are equilibrium points
4. C is a point of unstable equilibrium

(a) 1 and 2 (b) 1, 2 and 3 (c) 1, 2 and 4 (d) 1, 2, 3 and 4

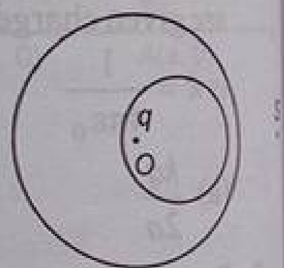
11. A point charge $q_1 = q$ is placed at point P. Another point charge $q_2 = -q$ is placed at point Q. At some point $R (R \neq P, R \neq Q)$, electric potential due to q_1 is V_1 and electric potential due to q_2 is V_2. Which of the following is correct?

(a) Only for some points $V_1 > V_2$
(b) Only for some points $V_2 > V_1$
(c) For all points $V_1 > V_2$
(d) For all points $V_2 > V_1$



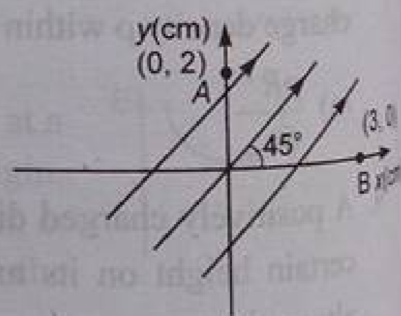
12. The variation of electric field between the two charges q_1 and q_2 along the line joining the charges is plotted against distance from q_1 (taking rightward direction of electric field as positive) as shown in the figure. Then the correct statement is

(a) q_1 and q_2 are positive and $q_1 < q_2$
(b) q_1 and q_2 are positive and $q_1 > q_2$
(c) q_1 is positive and q_2 is negative $q_1 < |q_2|$
(d) q_1 and q_2 are negative and $|q_1| < |q_2|$



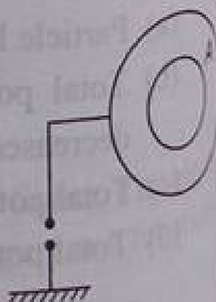
13. A charge q is placed at O in the cavity in a spherical uncharged conductor. Point S is outside the conductor. If q is displaced from O towards S (still remaining within the cavity)

(a) electric field at S will increase
(b) electric field at S will decrease
(c) electric field at S will first increase and then decrease
(d) electric field at S will not change



14. A uniform electric field of 400 V/m is directed at 45° above the x-axis as shown in the figure. The potential difference $V_A - V_B$ is given by

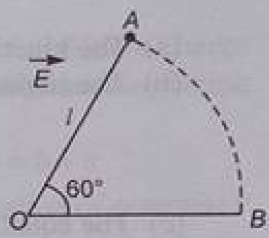
(a) 0
(b) 4 V
(c) 6.4 V
(d) 2.8 V



15. Initially the spheres A and B are at potential V_A and V_B respectively. Now sphere B is earthed by closing the switch. The potential of A will now become

(a) 0
(b) V_A
(c) $V_A - V_B$
(d) V_B

16. A particle of mass m and charge q is fastened to one end of a string of length l. The other end of the string is fixed to the point O. The whole system lies on a frictionless horizontal plane. Initially, the mass is at rest at A. A uniform electric field in the direction shown is then switched on. Then



(a) the speed of the particle when it reaches B is $\sqrt{\dfrac{2qEl}{m}}$

(b) the speed of the particle when it reaches B is $\sqrt{\dfrac{qEl}{m}}$,

(c) the tension in the string when the particle reaches at B is qE

(d) the tension in the string when the particle reaches at B is zero

17. A charged particle of mass m and charge q is released from rest from the position $(x_0, 0)$ in a uniform electric field $E_0\hat{\mathbf{j}}$. The angular momentum of the particle about origin

(a) is zero (b) is constant • (c) increases with time (d) decreases with time

18. A charge $+Q$ is uniformly distributed in a spherical volume of radius R. A particle of charge $+q$ and mass m projected with velocity v_0 from the surface of the spherical volume to its centre inside a smooth tunnel dug across the sphere. The minimum value of v_0 such that it just reaches the centre (assume that there is no resistance on the particle except electrostatic force) of the spherical volume is

(a) $\sqrt{\dfrac{Qq}{2\pi\varepsilon_0 mR}}$ (b) $\sqrt{\dfrac{Qq}{\pi\varepsilon_0 mR}}$ (c) $\sqrt{\dfrac{2Qq}{\pi\varepsilon_0 mR}}$ (d) $\sqrt{\dfrac{Qq}{4\pi\varepsilon_0 mR}}$

19. Two identical coaxial rings each of radius R are separated by a distance of $\sqrt{3}R$. They are uniformly charged with charges $+Q$ and $-Q$ respectively. The minimum kinetic energy with which a charged particle (charge $+q$) should be projected from the centre of the negatively charged ring along the axis of the rings such that it reaches the centre of the positively charged ring is

(a) $\dfrac{Qq}{4\pi\varepsilon_0 R}$ (b) $\dfrac{Qq}{2\pi\varepsilon_0 R}$ (c) $\dfrac{Qq}{8\pi\varepsilon_0 R}$ (d) $\dfrac{3Qq}{4\pi\varepsilon_0 R}$

20. A uniform electric field exists in x-y plane. The potential of points A(2m, 2m), B(−2m, 2m) and C(2m, 4m) are 4 V, 16 V and 12 V respectively. The electric field is

(a) $(4\hat{\mathbf{i}} + 5\hat{\mathbf{j}})$ V/m (b) $(3\hat{\mathbf{i}} + 4\hat{\mathbf{j}})$ V/m (c) $-(3\hat{\mathbf{i}} + 4\hat{\mathbf{j}})$ V/m (d) $(3\hat{\mathbf{i}} - 4\hat{\mathbf{j}})$ V/m

21. Two fixed charges $-2Q$ and $+Q$ are located at points $(-3a, 0)$ and $(+3a, 0)$ respectively. Then which of the following statement is correct?

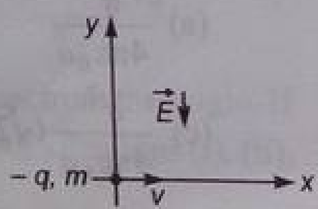
(a) Points where the electric potential due to the two charges is zero in x-y plane, lie on a circle of radius $4a$ and centre $(5a, 0)$

(b) Potential is zero at $x = a$ and $x = 9a$

(c) Both (a) and (b) are wrong

(d) Both (a) and (b) are correct

22. A particle of mass m and charge $-q$ is projected from the origin with a horizontal speed v into an electric field of intensity E directed downward. Choose the **wrong** statement. Neglect gravity



(a) The kinetic energy after a displacement y is qEy

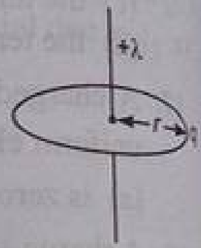
(b) The horizontal and vertical components of acceleration are

$$a_x = 0, a_y = \frac{qE}{m}$$

(c) The equation of trajectory is $y = \frac{1}{2}\left(\frac{qEx^2}{mv^2}\right)$

(d) The horizontal and vertical displacements x and y after a time t are $x = vt$ and $y = \frac{1}{2}a_y t^2$

23. A particle of charge $-q$ and mass m moves in a circle of radius r around an infinitely long line charge of linear charge density $+\lambda$. Then time period will be

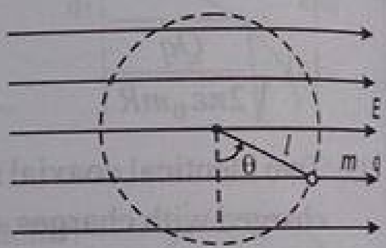


(a) $T = 2\pi r\sqrt{\frac{m}{2k\lambda q}}$ (b) $T^2 = \frac{4\pi^2 m}{2k\lambda q} r^3$

(c) $T = \frac{1}{2\pi r}\sqrt{\frac{2k\lambda q}{m}}$ (d) $T = \frac{1}{2\pi r}\sqrt{\frac{m}{2k\lambda q}}$

where $k = \frac{1}{4\pi\varepsilon_0}$

24. A small ball of mass m and charge $+q$ tied with a string of length l, rotating in a vertical circle under gravity and a uniform horizontal electric field E as shown. The tension in the string will be minimum for



(a) $\theta = \tan^{-1}\left(\frac{qE}{mg}\right)$ (b) $\theta = \pi$

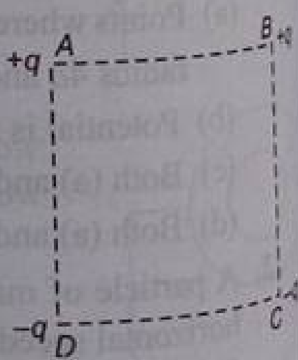
(c) $\theta = 0°$ (d) $\theta = \pi + \tan^{-1}\left(\frac{qE}{mg}\right)$

25. Three concentric spherical metallic shells A, B and C of radii a, b and $c (c > b > a)$ have charge densities $\sigma, -\sigma$ and σ respectively. The potential of shell B is

(a) $(a + b + c)\frac{\sigma}{\varepsilon_0}$ (b) $\left(\frac{a^2}{b} - b + c\right)\frac{\sigma}{\varepsilon_0}$

(c) $\left(\frac{a^2}{c} - \frac{b^2}{c} + c\right)\frac{\sigma}{\varepsilon_0}$ (d) $\frac{\sigma c}{\varepsilon_0}$

26. Four point charges A, B, C and D are placed at the four corners of a square of side a. The energy required to take the charges C and D to infinity (they are also infinitely separated from each other) is



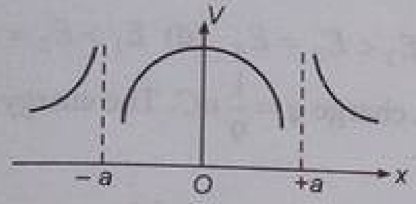
(a) $\frac{q^2}{4\pi\varepsilon_0 a}$ (b) $\frac{2q^2}{\pi\varepsilon_0 a}$

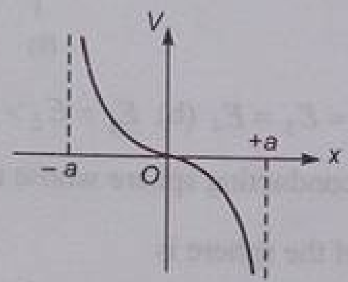
(c) $\frac{q^2}{4\pi\varepsilon_0 a}(\sqrt{2} + 1)$ (d) $\frac{q^2}{4\pi\varepsilon_0 a}(\sqrt{2} - 1)$

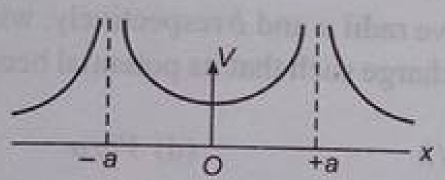
27. Three concentric spherical metallic shells A, B and C of radii a, b and $c (a < b < c)$ have charge densities σ, $-\sigma$ and σ, respectively. If the shells A and C are at the same potential then the relation between a, b and c is

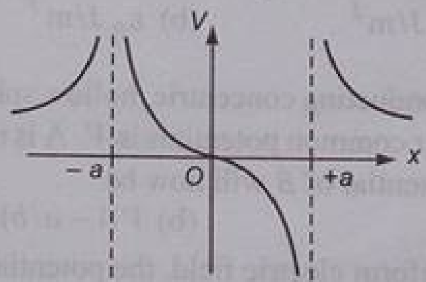
(a) $a + b + c = 0$ (b) $a + c = b$ (c) $a + b = c$ (d) $a = b + c$

28. Two identical positive charges are placed at $x = -a$ and $x = a$. The correct variation of potential V along the x-axis is given by

(a)


(b)


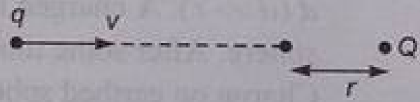
(c)


(d)


29. Two identical charges are placed at the two corners of an equilateral triangle. The potential energy of the system is U. The work done in bringing an identical charge from infinity to the third vertex is

(a) U (b) $2U$ (c) $3U$ (d) $4U$

30. A charged particle q is shot from a large distance towards another charged particle Q which is fixed, with a speed v. It approaches Q up to a closest distance r and then returns. If q were given a speed $2v$, the distance of approach would be

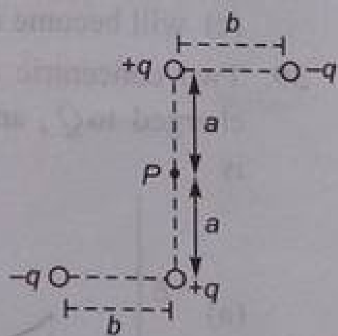


(a) r (b) $2r$ (c) $r/2$ (d) $r/4$

31. Two identical charged spheres are suspended by strings of equal length. The strings make an angle of 30° with each other. When suspended in a liquid of density 0.8 g/cc, the angle remains the same. The dielectric constant of the liquid is [density of the material of sphere is 1.6 g/cc]

(a) 2 (b) 4 (c) 2.5 (d) 3.5

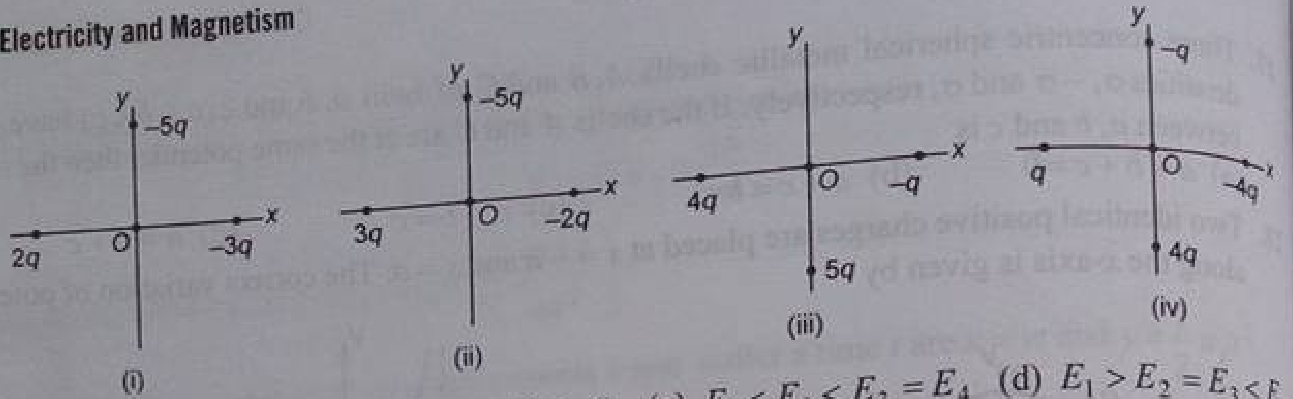
32. The electrostatic potential due to the charge configuration at point P as shown in figure for $b << a$ is



(a) $\dfrac{2q}{4\pi\varepsilon_0 a}$ (b) $\dfrac{2qb^2}{4\pi\varepsilon_0 a^3}$

(c) $\dfrac{qb^2}{4\pi\varepsilon_0 a^3}$ (d) zero

33. The figure shows four situations in which charged particles are at equal distances from the origin. If E_1, E_2, E_3 and E_4 be the magnitude of the net electric fields at the origin in four situations (i), (ii), (iii) and (iv) respectively, then



(a) $E_1 = E_2 = E_3 = E_4$ (b) $E_1 = E_2 > E_3 > E_4$ (c) $E_1 < E_2 < E_3 = E_4$ (d) $E_1 > E_2 = E_3 < E_4$

34. An isolated conducting sphere whose radius $R = 1$ m has a charge $q = \frac{1}{9} nC$. The energy density at the surface of the sphere is

(a) $\frac{\varepsilon_0}{2}$ J/m^3 (b) ε_0 J/m^3 (c) $2\varepsilon_0$ J/m^3 (d) $\frac{\varepsilon_0}{3}$ J/m^3

35. Two conducting concentric, hollow spheres A and B have radii a and b respectively, with A inside B. Their common potentials is V. A is now given some charge such that its potential becomes zero. The potential of B will now be

(a) 0 (b) $V(1-a/b)$ (c) Va/b (d) Vb/a

36. In a uniform electric field, the potential is 10 V at the origin of coordinates and 8 V at each of the points (1, 0, 0), (0, 1, 0) and (0, 0, 1). The potential at the point (1, 1, 1) will be

(a) 0 (b) 4 V (c) 8 V (d) 10 V

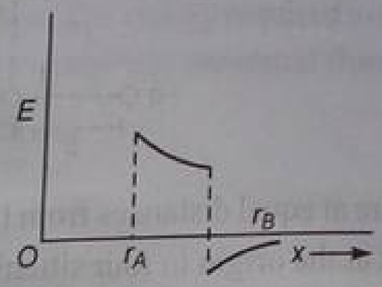
37. There are two uncharged identical metallic spheres 1 and 2 of radius r separated by a distance d ($d >> r$). A charged metallic sphere of same radius having charge q is touched with one of the sphere. After some time it is moved away from the system. Now the uncharged sphere is earthed. Charge on earthed sphere is

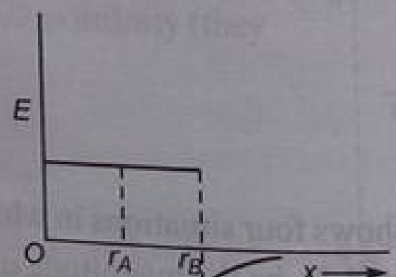
(a) $+\frac{q}{2}$ (b) $-\frac{q}{2}$ (c) $-\frac{qr}{2d}$ (d) $-\frac{qd}{2r}$

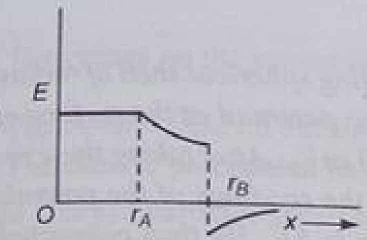
38. Figure shows a closed dotted surface which intersects a conducting uncharged sphere. If a positive charges is placed at the point P, the flux of the electric field through the closed surface

(a) will remain zero (b) will become positive
(c) will become negative (d) data insufficient

39. Two concentric conducting thin spherical shells A and B having radii r_A and r_B ($r_B > r_A$) are charged to Q_A and $-Q_B$ ($|Q_B| > |Q_A|$). The electrical field along a line passing through the centre is

(a)


(b)


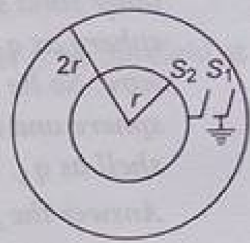
(c) 

(d) None of these

40. The electric potential at a point (x, y) in the x-y plane is given by $V = -Kxy$. The field intensity at a distance r in this plane, from the origin is proportional to

(a) r^2 (b) r (c) $1/r$ (d) $1/r^2$

Passage (Q. No. 41 to Q. No. 43)



There are two concentric spherical shell of radii r *and* $2r$. *Initially a charge* Q *is given to the inner shell and both the switches are open.*

41. If switch S_1 is closed and then opened, charge on the outer shell will be

(a) Q (b) $Q/2$ (c) $-Q$ (d) $-Q/2$

42. Now S_2 is closed and opened. The charge flowing through the switch S_2 in the process is

(a) Q (b) $Q/4$ (c) $Q/2$ (d) $2Q/3$

43. The two steps of the above two problems are repeated n times, the potential difference between the shells will be

(a) $\frac{1}{2^{n+1}}\left[\frac{Q}{4\pi\varepsilon_0 r}\right]$ (b) $\frac{1}{2^n}\left[\frac{Q}{4\pi\varepsilon_0 r}\right]$ (c) $\frac{1}{2^n}\left[\frac{Q}{2\pi\varepsilon_0 r}\right]$ (d) $\frac{1}{2^{n-1}}\left[\frac{Q}{2\pi\varepsilon_0 r}\right]$

Passage (Q. No. 44 to Q. No. 47)

A sphere of charge of radius R carries a positive charge whose volume charge density depends only on the distance r from the ball's centre as $\rho = \rho_0\left(1 - \frac{r}{R}\right)$. *Where* ρ_0 *is a constant. Assume* ε *as the permittivity of space.*

44. The magnitude of electric field as a function of the distance r inside the sphere is given by

(a) $E = \frac{\rho_0}{\varepsilon}\left[\frac{r}{3} - \frac{r^2}{4R}\right]$ (b) $E = \frac{\rho_0}{\varepsilon}\left[\frac{r}{4} - \frac{r^2}{3R}\right]$ (c) $E = \frac{\rho_0}{\varepsilon}\left[\frac{r}{3} + \frac{r^2}{4R}\right]$ (d) $E = \frac{\rho_0}{\varepsilon}\left[\frac{r}{4} + \frac{r^2}{3R}\right]$

45. The magnitude of the electric field as a function of the distance r outside the ball is given by

(a) $E = \frac{\rho_0 R^3}{8\varepsilon r^2}$ (b) $E = \frac{\rho_0 R^3}{12\varepsilon r^2}$ (c) $E = \frac{\rho_0 R^2}{8\varepsilon r^3}$ (d) $E = \frac{\rho_0 R^2}{12\varepsilon r^3}$

46. The value of distance r_m at which electric field intensity is maximum, is given by

(a) $r_m = \frac{R}{3}$ (b) $r_m = \frac{3R}{2}$ (c) $r_m = \frac{2R}{3}$ (d) $r_m = \frac{4R}{3}$

47. The maximum electric field intensity is

(a) $E_m = \frac{\rho_0 R}{9\varepsilon}$ (b) $E_m = \frac{\rho_0 \varepsilon}{9R}$ (c) $E_m = \frac{\rho_0 R}{3\varepsilon}$ (d) $E_m = \frac{\rho_0 R}{6\varepsilon}$

Passage (Q. No. 48 to Q. No. 50)

A solid metallic sphere of radius a is surrounded by a conducting spherical shell of radius b (b > a). The solid sphere is given a charge Q. A student measures the potential at the surface of the solid sphere as V_a and the potential at the surface of spherical shell as V_b. After taking these readings, he decides to put charge of $-4Q$ on the shell. He then noted the readings of the potential of solid sphere and the shell and found that the potential difference is ΔV. He then connected the outer spherical shell to the earth by a conducting wire and found that the charge on the outer surface of the shell as q_1. He then decides to remove the earthing connection from the shell and earthed the inner solid sphere. Connecting the inner sphere with the earth he observes the charge on the solid sphere as q_2. He then wanted to check what happens if the two are connected by the conducting wire. So he removed the earthing connection and connected a conducting wire between the solid sphere and the spherical shell. After the connections were made he found the charge on the outer shell as q_3.

Answer the following questions based on the readings taken by the student at various stages.

48. Potential difference (ΔV) measured by the student between the inner solid sphere and outer shell after putting a charge $-4Q$ is

(a) $V_a - 3V_b$ (b) $3(V_a - V_b)$ (c) V_a (d) $V_a - V_b$

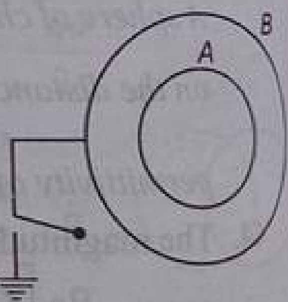
49. q_2 is

(a) Q (b) $Q\left(\frac{a}{b}\right)$ (c) $-4Q$ (d) zero

50. q_3 is

(a) $\frac{Q(a+b)}{a-b}$ (b) $\frac{Qa^2}{b}$ (c) $\frac{Q(a-b)}{b}$ (d) $-\frac{Qb}{a}$

More than One Correct Options



1. Two concentric shells have radii R and $2R$ charges q_A and q_B and potentials 2 V and (3/2) V respectively. Now shell B is earthed and let charges on them become q_A' and q_B'. Then

(a) $q_A/q_B = 1/2$

(b) $q_A'/q_B' = 1$

(c) potential of A after earthing becomes (3/2) V

(d) potential difference between A and B after earthing becomes $V/2$

2. A particle of mass 2 kg and charge 1 mC is projected vertically with a velocity 10 ms^{-1}. There is a uniform horizontal electric field of 10^4 N/C

(a) The horizontal range of the particle is 10 m

(b) The time of flight of the particle is 2 sec

(c) The maximum height reached is 5 m

(d) The horizontal range of the particle is 5 m

3. At the distance of 5 cm and 10 cm from surface of a uniformly charged solid sphere, the potentials are 100 V and 75 V respectively. Then

(a) Potential at its surface is 150 V

(b) The charge on the sphere is $\frac{50}{3} \times 10^{-10}$ C
(c) The electric field on the surface is 1500 V/m
(d) The electric potential at its centre is 25 V

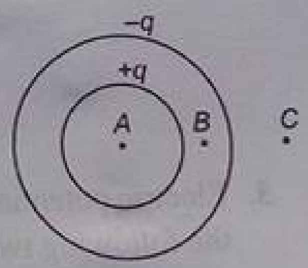
4. Three charged particles are in equilibrium under their electrostatic forces only. Then
(a) The particles must be collinear
(b) All the charges cannot have the same magnitude
(c) All the charges cannot have the same sign
(d) The equilibrium is unstable

5. Charges Q_1 and Q_2 lie inside and outside respectively of a closed surface S. Let E be the field at any point on S and ϕ be the flux of E over S
(a) If Q_1 changes, both E and ϕ will change
(b) If Q_2 changes, E will change but ϕ will not change
(c) If $Q_1 = 0$ and $Q_2 \neq 0$ then $E \neq 0$ but $\phi = 0$
(d) If $Q_1 \neq 0$ and $Q_2 = 0$ then $E = 0$ but $\phi \neq 0$

6. An electric dipole is placed at the centre of a sphere. Mark the correct options.
(a) The flux of the electric field through the sphere is zero
(b) The electric field is zero at every point of the sphere
(c) The electric field is not zero at any where on the sphere
(d) The electric field is zero on a circle on the sphere

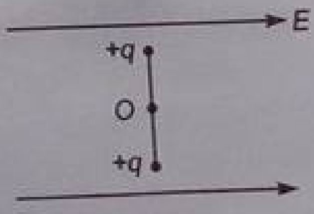
7. Mark the correct options.
(a) Gauss's law is valid only for uniform charge distributions
(b) Gauss's law is valid only for charges placed in vacuum
(c) The electric field calculated by Gauss's law is the field due to all the charges
(d) The flux of the electric field through a closed surface due to all the charges is equal to the flux due to the charges enclosed by the surface

8. Two concentric spherical shells have charges $+q$ and $-q$ as shown in figure. Choose the correct options



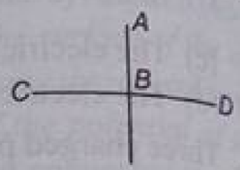
(a) At A electric field is zero, but electric potential is non-zero
(b) At B electric field and electric potential both are non-zero
(c) At C electric field is zero but electric potential is non-zero
(d) At C electric field and electric potential both are zero

9. A rod is hinged (free to rotate) at its centre O as shown in figure. Two point charges $+q$ and $+q$ are kept at its two ends. Rod is placed in uniform electric field E as shown. Space is gravity free. Choose the correct options.



(a) Net force from the hinge on the rod is zero
(b) Net force from the hinge on the rod is left wards
(c) Equilibrium of rod is neutral
(d) Equilibrium of rod is stable

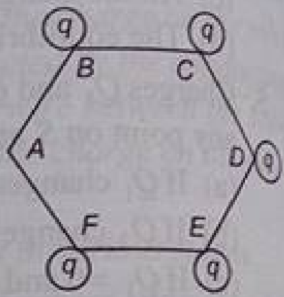
10. Two charges $+Q$ each are fixed at points C and D. Line AB is the bisector line of CD. A third charge $+q$ is moved from A to B, then from B to C.



(a) From A to B electrostatic potential energy will decrease
(b) From A to B electrostatic potential energy will increase
(c) From B to C electrostatic potential energy will increase
(d) From B to C electrostatic potential energy will decrease

Match the Columns

1. Five identical charges are kept at five vertices of a regular hexagon. Match the following two columns at centre of the hexagon. If in the given situation electric field at centre is E. Then



Column I	Column II
(a) If charge at B is removed then electric field will become	(p) $2E$
(b) If charge at C is removed then electric field will become	(q) E
(c) If charge at D is removed then electric field will become	(r) zero
(d) If charges at B and C both are removed then electric field will become	(s) $\sqrt{3}E$

Note *Only magnitudes of electric field are given.*

2. In an electric field $\vec{E} = (2\hat{i} + 4\hat{j})$ N/C, electric potential at origin is 0 V. Match the following two columns.

Column I	Column II
(a) Potential at (4m, 0)	(p) 8 V
(b) Potential at (–4m, 0)	(q) – 8 V
(c) Potential at (0, 4m)	(r) 16 V
(d) Potential at (0, – 4 m)	(s) – 16 V

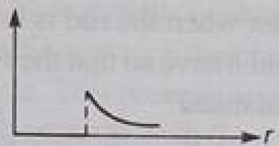
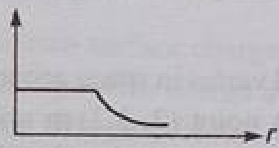
3. Electric potential on the surface of a solid sphere of charge is V. Radius of the sphere is 1m. Match the following two columns.

Column I	Column II
(a) Electric potential at $r = \frac{R}{2}$	(p) $\frac{V}{4}$
(b) Electric potential at $r = 2R$	(q) $\frac{V}{2}$
(c) Electric field at $r = \frac{R}{2}$	(r) $\frac{3V}{4}$
(d) Electric field at $r = 2R$	(s) None of these

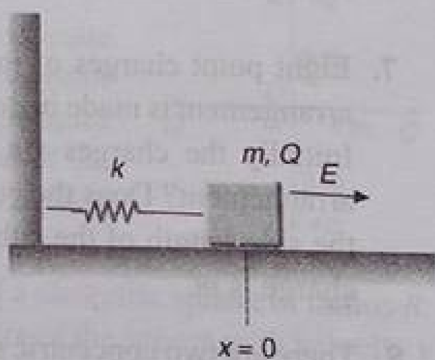
4. Match the following two columns.

Column I	Column II
(a) Electric potential	(p) $[MLT^{-3}A^{-1}]$
(b) Electrical field	(q) $[ML^3T^{-3}A^{-1}]$
(c) Electric flux	(r) $[ML^2T^{-3}A^{-1}]$
(d) Permittivity of free space	(s) None of these

5. Match the following two columns.

Column I	Column II
(a) Electric field due to charged spherical shell	(p) 
(b) Electric potential due to charged spherical shell	(q) 
(c) Electric field due to charged solid sphere	(r) 
(d) Electric potential due to charged solid sphere	(s) None of these

ubjective Questions (Level 2)



1. A 4.00 kg block carrying a charge $Q = 50.0\ \mu C$ is connected to a spring for which $k = 100$ N/m. The block lies on a frictionless horizontal track, and the system is immersed in a uniform electric field of magnitude $E = 5.00 \times 10^5$ V/m, directed as shown in figure. If the block is released from rest when the spring is unstretched (at $x = 0$).
   (a) By what maximum amount does the spring expand?
   (b) What is the equilibrium position of the block?
   (c) Show that the block's motion is simple harmonic and determine its period.
   (d) Repeat part (a) if the coefficient of kinetic friction between block and surface is 0.200.

. A particle of mass m and charge $-Q$ is constrained to move along the axis of a ring of radius a. The ring carries a uniform charge density $+\lambda$ along its length. Initially the particle is in the centre of the ring where the force on it is zero. Show that the period of oscillation of the particle when it is displaced slightly from its equilibrium position is given by

$$T = 2\pi\sqrt{\frac{2\varepsilon_0 ma^2}{\lambda Q}}$$

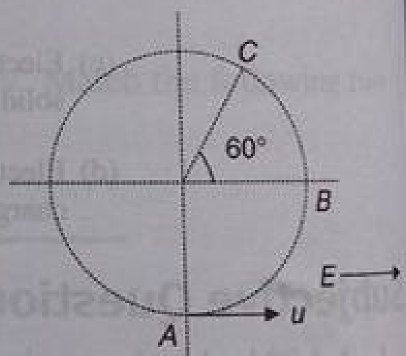
3. Three identical, conducting plane parallel plates, each of area A are held with equal separation d between successive surfaces. Charges $Q, 2Q$, and $3Q$ are placed on them. Neglecting edge effects, find the distribution of charges on the six surfaces.

4. A long non-conducting, massless rod of length L pivoted at its centre and balanced with a weight W at a distance x from the left end. At the left and right ends of the rod are attached small conducting spheres with positive charges q and $2q$ respectively. A distance h directly beneath each of these spheres is a fixed sphere with positive charge Q.
   (a) Find the distance x when the rod is horizontal and balanced.
   (b) What value should h have so that the rod exerts no vertical force on the bearing when the rod is horizontal and balanced?

Note *Ignore the force between Q (beneath q) and 2q and the force between Q (beneath 2q) and q. Also the force between Q and Q.*

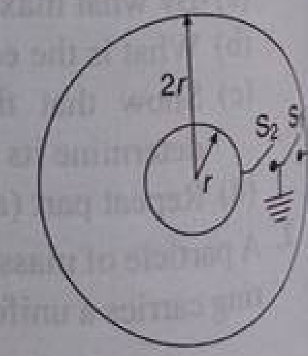
5. The electric potential varies in space according to the relation $V = 3x + 4y$. A particle of mass 10 kg starts from rest from point (2, 3.2) m under the influence of this field. Find the velocity of the particle when it crosses the x-axis. The charge on the particle is $+1\ \mu C$. Assume $V\ (x, y)$ are in SI units.

6. A simple pendulum with a bob of mass $m = 1$ kg, charge $q = 5\ \mu C$ and string length $l = 1$ m is given a horizontal velocity u in a uniform electric field $E = 2 \times 10^6$ V/m at its bottommost point A, as shown in figure. It is given that the speed u is such that the particle leaves the circle at point C. Find the speed u (Take $g = 10\ m/s^2$)

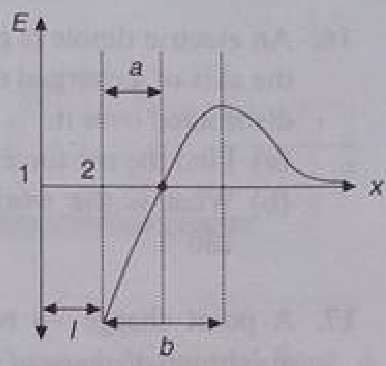


7. Eight point charges of magnitude Q are arranged to form the corners of a cube of side L. The arrangement is made in manner such that the nearest neighbour of any charge has the opposite sign. Initially the charges are held at rest. If the system is let free to move, what happens to the arrangement? Does the cube-shape shrink or expand? Calculate the velocity of each charge when the side-length of the cube formation changes from L to nL. Assume that the mass of each point charge is m.

. There are two concentric spherical shells of radii r and $2r$. Initially a charge Q is given to the inner shell. Now, switch S_1 is closed and opened then S_2 is closed and opened and the process is repeated n times for both the keys alternatively. Find the final potential difference between the shells.



9. Two point charges Q_1 and Q_2 are positioned at points 1 and 2. The field intensity to the right of the charge Q_2 on the line that passes through the two charges varies according to a law that is represented schematically in the figure. The field intensity is assumed to be positive if its direction coincides with the positive direction on the x-axis. The distance between the charges is l.



   (a) Find the sign of each charge.

   (b) Find the ratio of the absolute values of the charges $\left|\frac{Q_1}{Q_2}\right|$

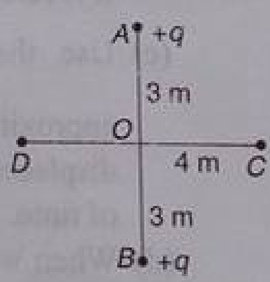
   (c) Find the value of b where the field intensity is maximum.

10. A conducting sphere S_1 of radius r is attached to an insulting handle. Another conducting sphere S_2 of radius R ($> r$) is mounted on an insulating stand, S_2 is initially uncharged. S_1 is given a charge Q. Brought into contact with S_2 and removed. S_1 is recharged such that the charge on it is again Q and it is again brought into contact with S_2 and removed. This procedure is repeated n times.
    (a) Find the electrostatic energy of S_2 after n such contacts with S_1.
    (b) What is the limiting value of this energy as $n \to \infty$?

11. A non-conducting disc of radius a and uniform positive surface charge density σ is placed on the ground with its axis vertical. A particle of mass m and positive charge q is dropped, along the axis of the disc from a height H with zero initial velocity. The particle has $q/m = 4\varepsilon_0 g/\sigma$.
    (a) Find the value of H if the particle just reaches the disc.
    (b) Sketch the potential energy of the particle as a function of its height and find its equilibrium position.

12. A proton of mass m and accelerated by a potential difference V gets into a uniform electric field of a parallel plate capacitor parallel to plates of length l at mid point of its separation between plates. The field strength in it varies with time as $E = at$, where a is a positive constant. Find the angle of deviation of the proton as it comes out of the capacitor. (Assume that it does not collide with any of the plates.)

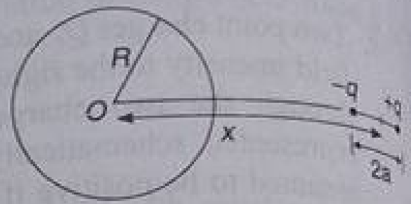
13. Two fixed, equal, positive charges, each of magnitude 5×10^{-5} C are located at points A and B separated by a distance of 6 m. An equal and opposite charge moves towards them along the line COD, the perpendicular bisector of the line AB. The moving charge when it reaches the point C at a distance of 4 m from O, has a kinetic energy of 4 J. Calculate the distance of the farthest point D which the negative charge will reach before returning towards C.



14. Positive charge Q is uniformly distributed throughout the volume of a dielectric sphere of radius R. A point mass having charge $+q$ and mass m is fired towards the centre of the sphere with velocity v from a point A at distance $r (r > R)$ from the centre of the sphere. Find the minimum velocity v so that it can penetrate $R/2$ distance of the sphere. Neglect any resistance other than electric interaction. Charge on the small mass remains constant throughout the motion.

15. Two concentric rings placed in a gravity free region in yz-plane one of radius R carries a charge $+Q$ and second of radius $4R$ and charge $-8Q$ distributed uniformly over it. Find the minimum velocity with which a point charge of mass m and charge $+q$ should be projected from a point at a distance $3R$ from the centre of rings on its axis so that it will reach to the centre of the rings.

16. An electric dipole is placed at a distance x from centre O on the axis of a charged ring of radius R and charge Q uniformly distributed over it.

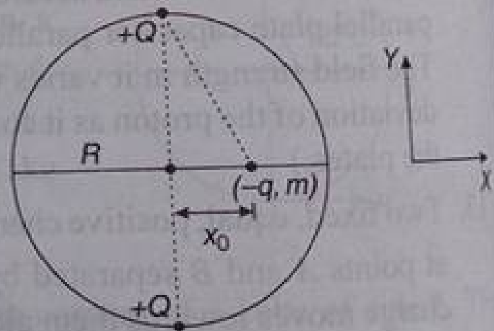


(a) Find the net force acting on the dipole.
(b) What is the work done in rotating the dipole through 180°?

17. A point charge $-q$ revolves around a fixed charge $+Q$ in elliptical orbit. The minimum and maximum distance of q from Q are r_1 and r_2, respectively. The mass of revolving particle is m. $Q >> q$ and assume no gravitational effects. Find the velocity of q at positions when it is at r_1 and r_2 distance from Q.

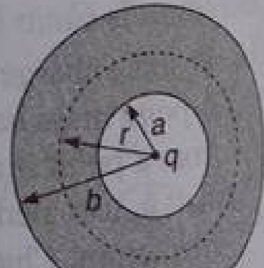
18. Three concentric, thin, spherical, metallic shells have radii 1, 2, and 4 cm and they are held at potentials 10, 0 and 40 V respectively. Taking the origin at the common centre, calculate the following:
(a) Potential at $r = 1.25$ cm
(b) Potential at $r = 2.5$ cm
(c) Electric field at $r = 1.25$ cm

19. A thin insulating wire is stretched along the diameter of an insulated circular hoop of radius R. A small bead of mass m and charge $-q$ is threaded onto the wire. Two small identical charges are tied to the hoop at points opposite to each other, so that the diameter passing through them is perpendicular to the thread (see figure). The bead is released at a point which is a distance x_0 from the centre of the hoop. Assume that $x_0 << R$.



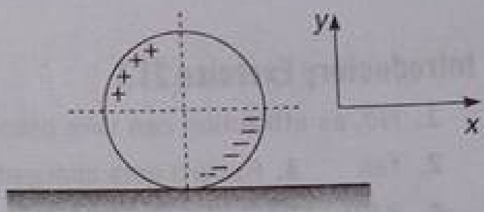
(a) What is the resultant force acting on the charged bead?
(b) Describe (qualitatively) the motion of the bead after it is released.
(c) Use the assumption that $\frac{x}{R} << 1$ to obtain an approximate equation of motion, and find the displacement and velocity of the bead as functions of time.
(d) When will the velocity of the bead will become zero for the first time?

20. The region between two concentric spheres of radii a and $b\,(> a)$ contains volume charge density $\rho(r) = \frac{C}{r}$, where C is a constant and r is the radial distance, as shown in figure. A point charge q is placed at the origin, $r = 0$.



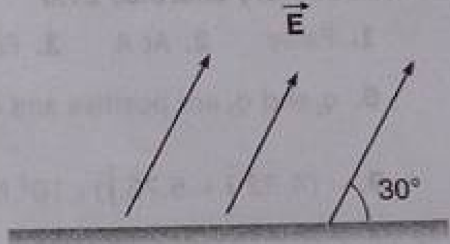
Find the value of C for which the electric field in the region between the spheres is constant (i.e., r independent).

21. A non-conducting ring of mass m and radius R is charged as shown. The charge density, *i.e.*, charge per unit length is λ. It is then placed on a rough non-conducting horizontal plane. At time $t=0$, a uniform electric field $\vec{\mathbf{E}}=E_0\hat{\mathbf{i}}$ is switched on and the ring starts rolling without sliding. Determine the friction force (magnitude and direction) acting on the ring when it starts moving.



22. A rectangular tank of mass m_0 and charge Q over it is placed over a smooth horizontal floor. A horizontal electric field E exist in the region. Rain drops are falling vertically in the tank at the constant rate of n drops per second. Mass of each drop is m. Find velocity of tank as function of time.

23. In a region an electric field $E=15$ N/C making an angle of 30° with the horizontal plane is present. A ball having charge 2C, mass 3 kg and coefficient of restitution with ground 1/2 is projected at an angle of 30° with the horizontal in the direction of electric field with speed 20 m/s. Find the horizontal distance travelled by ball from first drop to the second drop.



ANSWERS

Introductory Exercise 21.1

1. No, as attraction can take place between a charged and an uncharged body too.
2. Yes 3. Record gets charged when cleaned and then by induction, it attracts dust particles.
4. 2.89×10^5 C

Introductory Exercise 21.2

1. 2.27×10^{39} 2. $M^{-1} L^{-3} T^4 A^2$, $\frac{C}{V\text{-}m}$ 3. $\frac{\sqrt{3}}{4\pi\varepsilon_0}\left(\frac{q}{a}\right)^2$ 4. $\frac{1}{2\pi\varepsilon_0}\cdot\left(\frac{q}{a}\right)^2$ 5. No
6. Induction → Conduction → Repulsion 7. Yes 8. No 9. $(-4\hat{i} + 3\hat{j})$ N

Introductory Exercise 21.3

1. False 2. At A 3. False 4. False 5. 5.31×10^{-11} C/m^2
6. q_1 and q_3 are positive and q_2 is negative 7. $\frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{a^2}$ 8. $\frac{qx}{8\pi^2\varepsilon_0 R^3}$
9. $-(4.32\,\hat{i} + 5.76\,\hat{j}) \times 10^2$ N/C

Introductory Exercise 21.4

1. 18.9 m/s 2. -9 mJ 3. -10.6×10^{-8} J 4. No, Yes

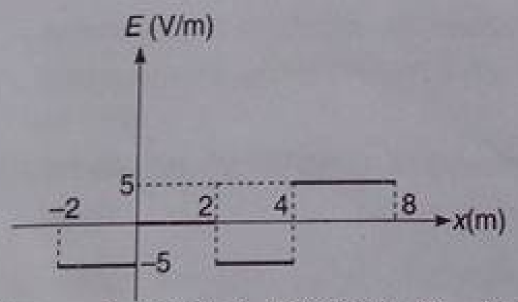
Introductory Exercise 21.5

1. 1.2×10^3 V 2. (a) $\frac{C}{m^2}$ (b) $\frac{1}{4\pi\varepsilon_0} \times \alpha\left[L - d\ln\left(1 + \frac{L}{d}\right)\right]$
3. $V = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{2l}\ln\left(\frac{\sqrt{l^2 + d^2} + l}{\sqrt{l^2 + d^2} - l}\right)$ 4. $\frac{Qq}{2\pi\varepsilon_0 L}$

Introductory Exercise 21.6

1. (a) $\vec{E} = -2a(x\hat{i} - y\hat{j})$ (b) $\vec{E} = -a(y\hat{i} + x\hat{j})$

2.



3. False 4. (a) Zero (b) 20 V (c) -20 V (d) -20 V

Introductory Exercise 21.8

1. (a) Zero (b) $\frac{q}{\varepsilon_0}$ (c) $\frac{q}{2\varepsilon_0}$ 2. $\frac{q}{24\varepsilon_0}$, Zero 3. True 4. (a) Zero (b) $\pi R^2 E$
5. $\frac{q_0}{3\varepsilon_0}$ 6. Zero

Introductory Exercise 21.9

1. 2q, Zero

2.

	A	B	C
Inner Surface	0	$-\frac{6}{11}q$	$\frac{18}{11}q$
Outer Surface	$\frac{6}{11}q$	$-\frac{18}{11}q$	$\frac{9}{11}q$

3.

	A	B	C
Inner Surface	$-q$	$-2q$	$\frac{4}{3}q$
Outer Surface	$2q$	$-\frac{4}{3}q$	$\frac{2}{3}q$

AIEEE Corner

Subjective Questions (Level 1)

1. $q=\frac{Q}{2}$ **2.** 2.3×10^{-24} N **3.** $\frac{F_e}{F_g}=3.1\times10^{35}$ **4.** $\pm3\,\mu C, \mp1\,\mu C$

5. (a) $q_1=9q_2$ (b) $q_1=-25q_2$

6. (a) Third charge is $-\frac{4q}{9}$ at a distance of $\frac{L}{3}$ from q between the two charges.

7. $\left(\frac{4\pi\varepsilon_0 mgR^2}{\sqrt{3}}\right)^{1/2}$ **8.** 3.3×10^{-8} C **9.** $\frac{q}{4\pi\varepsilon_0 a^2}$ **10.** $(2\sqrt{2}+1)\frac{q}{8\pi\varepsilon_0 a^2}$

11. $(14\hat{j}-11\hat{i})$ N/C **12.** $\frac{\lambda}{2\pi\varepsilon_0 R}$ **13.** $\frac{Q}{2\pi\varepsilon_0 a\sqrt{L^2+4a^2}}$

14. (a) Along positive y-axis (b) Along positive x-axis (c) Along positive y-axis

15. 9.30 **16.** (a) 7.1 cm (b) 2.84×10^{-8} s (c) 0.11 **17.** 312.5 m

18. (a) 37° and 53° (b) 1.66×10^{-7} s, 2.2×10^{-7} s

19. (a) $(-2.1\times10^{13}\,\hat{j})$ m/s^2 (b) $(1.5\hat{i}+2.0\hat{j})\times10^5$ m/s

20. At $x=40$ cm and $x=-200$ cm **21.** $V=2.634\frac{Q}{4\pi\varepsilon_0 a}$ **22.** (a) -6×10^{-4} J (b) 50 V

23. 7.42 m/s, faster **24.** (a) $\frac{-5Q}{4\pi\varepsilon_0 R}$ (b) $\frac{-5Q}{4\pi\varepsilon_0\sqrt{R^2+z^2}}$ **25.** -0.356 J

26. (a) -3.6×10^{-7} J (b) $x=0.0743$ m **27.** $-q/2$ **28.** (a) zero (b) -20 kV

29. (a) -80 V (b) 120 V (c) 0 V **30.** (a) -80 V (b) -40 V

31. (a) $MT^{-3}I^{-1}$ (b) $-A\{(y+z)\hat{i}+(x+z)\hat{j}+(x+y)\hat{k}\}$ (c) 35 N/C **32.** -100 V

33. (a) $E_x=-Ay+2Bx, E_y=-Ax-C, E_z=0$. (b) $x=-C/A, y=-2BC/A^2$, any value of z

34. 3.19 nC **35.** (a) $-4.07 \times 10^5 \frac{\text{N-m}^2}{\text{C}}$ (b) 6.91 nC (c) No **36.** $240 \frac{\text{N-m}^2}{\text{C}}$ **37.** 2.2×10^{-12} C

39. (a) $\varphi_{s_1} = -CL^2, \varphi_{s_2} = -DL^2, \varphi_{s_3} = CL^2, \varphi_{s_4} = DL^2, \varphi_{s_5} = -BL^2, \varphi_{s_6} = BL^2$ (b) zero

40. $\frac{q}{\varepsilon_0}\left[1 - \frac{1}{\sqrt{1 + (R/l)^2}}\right]$ **41.** $\frac{q}{2\varepsilon_0}\left(1 - \frac{1}{\sqrt{2}}\right)$ **42.** $\frac{Q}{4\pi\varepsilon_0}\left(\frac{R + r}{R^2 + r^2}\right)$

43. (a) $V_A = \frac{\sigma}{\varepsilon_0}(a - b + c), V_B = \frac{\sigma}{\varepsilon_0}\left(\frac{a^2}{b} - b + c\right), V_C = \frac{\sigma}{\varepsilon_0}\left(\frac{a^2}{c} - \frac{b^2}{c} + c\right)$ (b) $c = a + b$

44. (a) $\frac{-Q}{4\pi a^2}, \frac{Q}{4\pi a^2}$ (b) $\frac{-Q}{4\pi a^2}, \frac{Q + q}{4\pi a^2}$ (c) $\frac{Q}{4\pi\varepsilon_0 x^2}$ in both situations

45. Inner surface of $B \to -q$, outer surface of $B \to \frac{b}{c}q$, inner surface of $C \to \left(\frac{-bq}{c}\right)$, outer surface of $C \to \left(\frac{b}{c} - 1\right)q$

46. (a) $\frac{Q}{2\pi\varepsilon_0 r^2}$ (b) $\frac{Q}{3\pi\varepsilon_0 R}$ (c) zero on inner and Q on outer (d) $\frac{Q}{3}$

47. (a) $\frac{Q}{4\pi\varepsilon_0 R}, \frac{Q}{6\pi\varepsilon_0 R}$ (b) $\frac{-Q}{25\pi\,\varepsilon_0 R^2}\hat{r}$ (c) $\frac{Q^2}{4\pi\,\varepsilon_0 R}$ (d) $\frac{Q + 2Q_1}{12\pi\,\varepsilon_0 R}, Q_1 = \frac{Q}{2}, Q_2 = \frac{7Q}{2}$ (e) $\frac{-3Q}{50\pi\,\varepsilon_0 R}\hat{r}$

Objective Questions (Level 1)

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

JEE Corner

Assertion and Reason

1. (b)	2. (a,b)	3. (d)	4. (b)	5. (b)	6. (d)	7. (a,b)	8. (d)	9. (c)	10. (b)

Objective Questions (Level 2)

1.(a)	2.(a)	3.(a)	4.(b)	5.(a)	6.(c)	7.(d)	8.(a)	9.(c)	10.(a)
11.(c)	12.(a)	13.(d)	14.(d)	15.(c)	16.(b)	17.(c)	18.(d)	19.(a)	20.(d)
21.(d)	22.(a)	23.(a)	24.(d)	25.(b)	26.(c)	27.(c)	28.(c)	29.(b)	30.(d)
31.(a)	32.(c)	33.(a)	34.(a)	35.(b)	36.(b)	37.(c)	38.(c)	39.(a)	40.(b)
41.(c)	42.(c)	43.(a)	44.(a)	45.(b)	46.(c)	47.(a)	48.(d)	49.(b)	50.(c)

More than One Correct Options

1.(a,d)	2.(a,b,c)	3.(a,b,c)	4.(all)	5.(a,b,c)	6.(a,c)	7.(c,d)	8.(a,b,d)	9.(b,c)	10.(b,c)

Match the Columns

1.	(a) → s	(b) → q	(c) → r	(d) → p
2.	(a) → q	(b) → p	(c) → s	(d) → r
3.	(a) → s	(b) → q	(c) → q	(d) → p
4.	(a) → r	(b) → p	(c) → q	(d) → s
5.	(a) → p	(b) → q	(c) → r	(d) → s

Subjective Questions (Level 2)

1. (a) 0.5 m (b) 0.25 m (c) 1.26 s (d) 0.34 m 3. $3Q, -2Q, 2Q, 0, 0, 3Q$

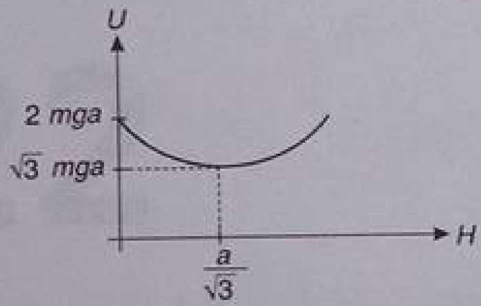
4. (a) $\frac{L}{2}\left[1+\frac{Qq}{(4\pi\varepsilon_0)Wh^2}\right]$ (b) $\sqrt{\frac{3Qq}{(4\pi\varepsilon_0)W}}$ 5. 2.0×10^{-3} m/s

6. 6 m/s 7. shrink, $\sqrt{\frac{Q^2(1-n)(3\sqrt{6}+\sqrt{2}-3\sqrt{3})}{4nm\pi L\varepsilon_0\sqrt{6}}}$ 8. $\frac{1}{2^{n+1}}\left[\frac{Q}{4\pi\varepsilon_0 r}\right]$

9. (a) Q_2 is negative and Q_1 is positive (b) $\left(\frac{l+a}{a}\right)^2$ (c) $\frac{l}{\left(\frac{l+a}{a}\right)^{2/3}-1}$

10. (a) $\frac{q_n^2}{8\pi\varepsilon_0 R}$ where $q_n=\frac{QR}{r}\left[1-\left(\frac{R}{R+r}\right)^n\right]$ (b) $\frac{Q^2R}{8\pi\varepsilon_0 r^2}$

11. (a) $\frac{4}{3}a$ (b) Equilibrium position is $H=\frac{a}{\sqrt{3}}$



12. $\theta=\tan^{-1}\left\{\frac{al^2}{4V}\sqrt{\frac{m}{2eV}}\right\}$ 13. $\sqrt{72}$ m 14. $\left[\frac{1}{2\pi\varepsilon_0}\frac{Qq}{Rm}\left(\frac{r-R}{r}+\frac{3}{8}\right)\right]^{\frac{1}{2}}$

15. $\sqrt{\frac{Qq}{2\pi\varepsilon_0 mR}\left(\frac{3\sqrt{10}-5}{5\sqrt{10}}\right)}$ 16. (a) $\frac{aqQ}{2\pi\varepsilon_0}\frac{R^2-2x^2}{(R^2+x^2)^{5/2}}$ (b) $\frac{aqQx}{\pi\varepsilon_0(R^2+x^2)^{3/2}}$

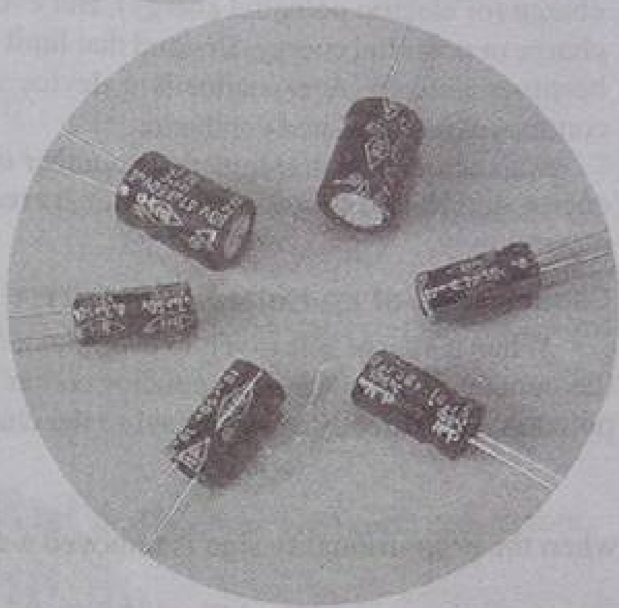
17. $\sqrt{\frac{Qqr_2}{2\pi\varepsilon_0 mr_1(r_1+r_2)}}$, $\sqrt{\frac{Qqr_1}{2\pi\varepsilon_0 mr_2(r_1+r_2)}}$ 18. (a) 6 V (b) 16 V (c) 1280 V/m

19. (a) $F=-\frac{2kQqx}{(R^2+x^2)^{3/2}}$ (b) Periodic between $\pm x_0$

(c) $x=x_0\cos\omega t$, $v=-\omega x_0\sin\omega t$ where $\omega=\sqrt{\frac{2Qqk}{mR^3}}$ (d) $t=\sqrt{\frac{\pi^2 mR^3}{2Qqk}}$ Here $k=\frac{1}{4\pi\varepsilon_0}$

20. $C=\frac{q}{2\pi a^2}$ 21. $f=\lambda RE_0$ along positive x-axis. 22. $v=QE\left(\frac{t}{m_0+mnt}\right)$ 23. $70\sqrt{3}$ m

22



Capacitors

Chapter Contents

Solved Examples

Example 1 *Three identical metallic plates are kept parallel to one another at a separation of a and b. The outer plates are connected by a thin conducting wire and a charge Q is placed on the central plate. Find final charges on all the six plate's surfaces.*

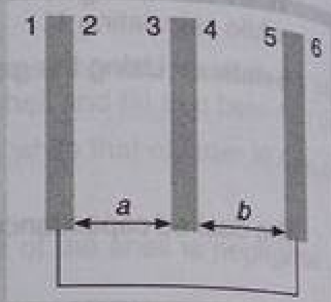


Fig. 22.122

Solution Let the charge distribution in all the six faces be as shown in figure. While distributing the charge on different faces, we have used the fact that two opposite faces have equal and opposite charges on them.

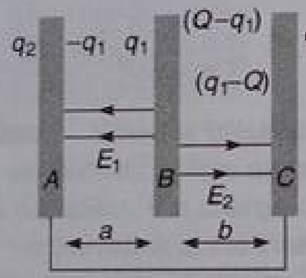


Fig. 22.123

Net charge on plates A and C is zero. Hence,

$$q_2 - q_1 + q_3 + q_1 - Q = 0$$

or

$$q_2 + q_3 = Q \qquad \text{...(i)}$$

Further A and C are at same potentials. Hence,

$$V_B - V_A = V_B - V_C \quad \text{or} \quad E_1 a = E_2 b$$

$$\therefore \quad \frac{q_1}{A\varepsilon_0} \cdot a = \frac{Q - q_1}{A\varepsilon_0} \cdot b \qquad (A = \text{Area of plates})$$

$$\therefore \quad q_1 a = (Q - q_1)\, b \quad \therefore \quad q_1 = \frac{Qb}{a+b} \qquad \text{...(ii)}$$

Electric field inside any conducting plate (say inside C) is zero. Therefore,

$$\frac{q_2}{2A\varepsilon_0} - \frac{q_1}{2A\varepsilon_0} + \frac{q_1}{2A\varepsilon_0} + \frac{Q - q_1}{2A\varepsilon_0} + \frac{q_1 - Q}{2A\varepsilon_0} - \frac{q_3}{2A\varepsilon_0} = 0$$

$$\therefore \quad q_2 - q_3 = 0 \qquad \text{...(iii)}$$

Solving these three equations, we get $q_1 = \dfrac{Qb}{a+b}$, $q_2 = q_3 = \dfrac{Q}{2}$

Hence, charge on different faces are as follows.

Face	Charge
1	$q_2 = \frac{Q}{2}$
2	$-q_1 = -\frac{Qb}{a+b}$
3	$q_1 = \frac{Qb}{a+b}$
4	$Q - q_1 = \frac{Qa}{a+b}$
5	$q_1 - Q = -\frac{Qa}{a+b}$
6	$q_3 = \frac{Q}{2}$

Ans.

Example 2 *In the circuit shown in figure, find the steady state charges on both the capacitors.*

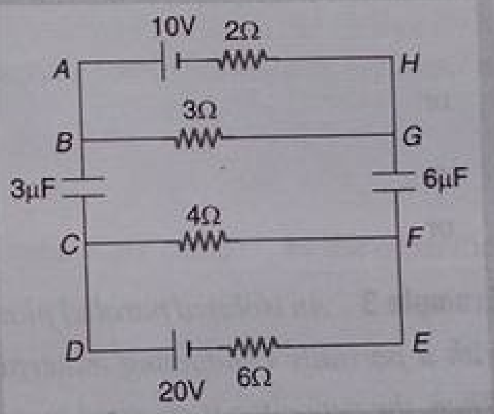


Fig. 22.124

HOW TO PROCEED *In steady state a capacitor offers an infinite resistance. Therefore, the two circuits ABGHA and CDEFC have no relation with each other. Hence, the battery of emf 10 V is not going to contribute any current in the lower circuit. Similarly, the battery of emf 20 V will not contribute to the current in the upper circuit. So first we will calculate the current in the two circuits, then find the potential difference V_{BG} and V_{CF} and finally we can connect two batteries of emf V_{BG} and V_{CF} across the capacitors to find the charges stored in them.*

Solution Current in the upper circuit $i_1 = \frac{10}{3+2} = 2\text{ A}$

$$\therefore \quad V_{BG} = V_B - V_G = 3i_1 = 3 \times 2 = 6 \text{ volt}$$

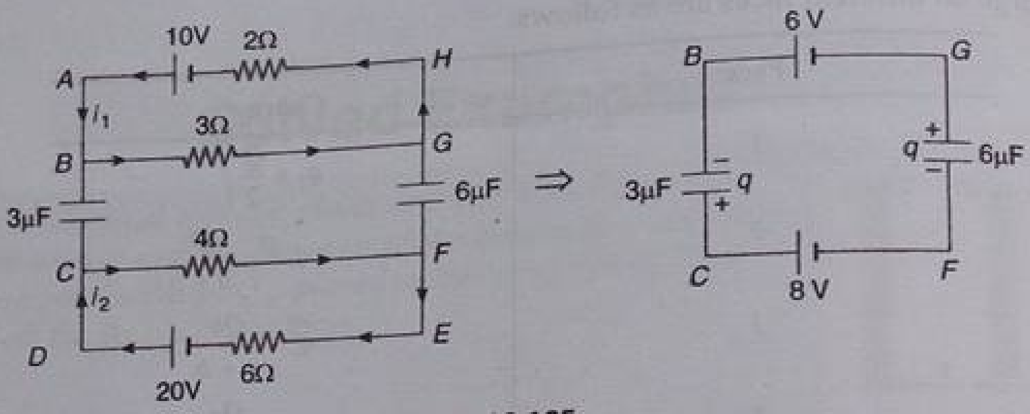


Fig. 22.125

Current in the lower circuit $$i_2 = \frac{20}{4+6} = 2\text{ A}$$

$\therefore$ $$V_{CF} = V_C - V_F = 4i_2 = 4 \times 2 = 8 \text{ volt}$$

Charge on both the capacitors will be same. Let it be q. Applying Kirchhoff's second law in loop $BGFCB$,

$$-6 - \frac{q}{6 \times 10^{-6}} + 8 - \frac{q}{3 \times 10^{-6}} = 0$$

or $$\frac{(10^6)q}{2} = 2$$

or $$q = 4 \times 10^{-6}\text{ C}$$

or $$q = 4\,\mu\text{C}$$ **Ans.**

Example 3 *An isolated parallel plate capacitor has circular plates of radius* 4.0 *cm. If the gap is filled with a partially conducting material of dielectric constant K and conductivity* $5.0 \times 10^{-14}\,\Omega^{-1} m^{-1}$. *When, the capacitor is charged to a surface charge density of* $15\,\mu C/cm^2$, *the initial current between the plates is* $1.0\,\mu A$?

(a) *Determine the value of dielectric constant K.*

(b) *If the total joule heating produced is 7500 J, determine the separation of the capacitor plates.*

Solution (a) This is basically a problem of discharging of a capacitor. Charge at any time t is,

$$q = q_0 e^{-t/\tau_c}$$

Here, q_0 = (area of plates) (surface charge density)

and discharging current, $$i = \left(\frac{-dq}{dt}\right) = \frac{q_0}{\tau_c} \cdot e^{-t/\tau_c} = i_0 e^{-t/\tau_c}$$

Here, $i_0 = \dfrac{q_0}{\tau_c} = \dfrac{q_0}{CR}$

$$C = \frac{K\varepsilon_0 A}{d} \quad \text{and} \quad R = \frac{d}{\sigma A}$$

$\therefore$ $$CR = \frac{K\varepsilon_0}{\sigma}$$

Therefore,
$$i_0 = \frac{q_0}{\frac{K\varepsilon_0}{\sigma}} = \frac{\sigma q_0}{K\varepsilon_0}$$

$\therefore$
$$K = \frac{\sigma q_0}{i_0 \varepsilon_0}$$

Substituting the values, we have
$$K = \frac{(5.0\times10^{-14})(\pi)(4.0)^2(15\times10^{-6})}{(1.0\times10^{-6})(8.86\times10^{-12})} = 4.25 \qquad \textbf{Ans.}$$

(b)
$$U = \frac{1}{2}\frac{q_0^2}{C} = \frac{1}{2}\frac{q_0^2}{\frac{K\varepsilon_0 A}{d}}$$

$$d = \frac{2K\varepsilon_0 AU}{q_0^2} = \frac{2\times4.25\times8.86\times10^{-12}\times\pi\times(4.0\times10^{-2})^2\times7500}{(15\times10^{-6}\times\pi\times4.0\times4.0)^2}$$
$$= 5.0\times10^{-3}\ \text{m} = 5.0\ \text{mm} \qquad \textbf{Ans.}$$

Example 4 *A conducting sphere S_1 of radius r is attached to an insulating handle. Another conducting sphere S_2 of radius R is mounted on an insulating stand, S_2 is initially uncharged. S_1 is given a charge Q brought into contact with S_2 and removed. S_1 is recharged such that the charge on it is again Q and it is again brought into contact with S_2 and removed. This procedure is repeated n times:*

(a) Find the electrostatic energy of S_2 after n such contacts with S_1.

(b) What is the limiting value of this energy as $n \to \infty$?

Solution Capacities of conducting spheres are in the ratio of their radii. Let C_1 and C_2 be the capacities of S_1 and S_2, then,
$$\frac{C_2}{C_1} = \frac{R}{r}$$

(a) Charges are distributed in the ratio of their capacities. Let in the first contact, charge acquired by S_2 is q_1. Therefore, charge on S_1 will be $Q - q_1$.

$\therefore$
$$\frac{q_1}{Q - q_1} = \frac{C_2}{C_1} = \frac{R}{r}$$

It implies that Q charge is to be distributed in S_2 and S_1 in the ratio of R/r.

$\therefore$
$$q_1 = Q\left(\frac{R}{R+r}\right) \qquad \text{...(i)}$$

In the second contact, S_1 again acquires the same charge Q.
Therefore, total charge in S_1 and S_2 will be
$$Q + q_1 = Q\left(1 + \frac{R}{R+r}\right)$$

This charge is again distributed in the same ratio. Therefore, charge on S_2 in second contact,
$$q_2 = Q\left(1 + \frac{R}{R+r}\right)\left(\frac{R}{R+r}\right) = Q\left[\frac{R}{R+r} + \left(\frac{R}{R+r}\right)^2\right]$$

Similarly,

$$q_3 = Q\left[\frac{R}{R+r} + \left(\frac{R}{R+r}\right)^2 + \left(\frac{R}{R+r}\right)^3\right]$$

and

$$q_n = Q\left[\frac{R}{R+r} + \left(\frac{R}{R+r}\right)^2 + \ldots \left(\frac{R}{R+r}\right)^n\right]$$

or

$$q_n = Q\frac{R}{r}\left[1 - \left(\frac{R}{R+r}\right)^n\right] \qquad \ldots\text{(i)} \qquad \left[\because S_n = \frac{a(1-r^n)}{(1-r)}\right]$$

Therefore, electrostatic energy of S_2 after n such contacts

$$U_n = \frac{q_n^2}{2C_2} = \frac{q_n^2}{2(4\pi\varepsilon_0 R)}$$

or

$$U_n = \frac{q_n^2}{8\pi\varepsilon_0 R}$$ **Ans.**

where q_n can be written from Eq. (i).

(b)

$$q_n = \frac{QR}{R+r}\left[1 + \frac{R}{R+r} + \ldots + \left(\frac{R}{R+r}\right)^{n-1}\right] \quad \text{as } n \to \infty$$

$$q_\infty = \frac{QR}{R+r}\left(\frac{1}{1 - \frac{R}{R+r}}\right) = \frac{QR}{R+r}\cdot\left(\frac{R+r}{r}\right) = Q\frac{R}{r}; \qquad \left[S_\infty = \frac{a}{1-r}\right]$$

$\because$

$$U_\infty = \frac{q_\infty^2}{2C_2} = \frac{Q^2R^2/r^2}{8\pi\varepsilon_0 R}$$

or

$$U_\infty = \frac{Q^2R}{8\pi\varepsilon_0 r^2}$$ **Ans.**

Spherical Capacitors

Example 5 *Three concentric conducting shells A, B and C of radii a, b and c are as shown in figure. A dielectric of dielectric constant K is filled between A and B. Find the capacitance between A and C.*

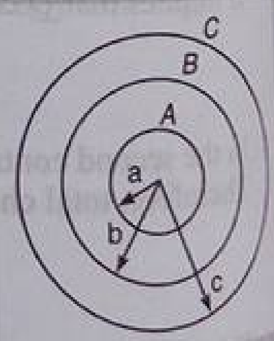


Fig. 22.126

HOW TO PROCEED *When the dielectric is filled between A and B, the electric field will change in this region. Therefore the potential difference and hence the capacitance of the system will change. So, first* *find the electric field E(r) in the region $a \le r \le c$. Then find the P.D (V) between A and C and finally the capacitance of the system will be,*

$$C = \frac{q}{V}$$

Here, q = charge on A

Solution
$$E(r) = \frac{q}{4\pi\varepsilon_0 K r^2} \quad \text{for } a \le r \le b$$

$$= \frac{q}{4\pi\varepsilon_0 r^2} \quad \text{for } b \le r \le c$$

Using,
$$dV = -\int \vec{E} \cdot d\vec{r}$$

the P.D between A and C is,

$$\therefore \quad V = V_A - V_C = -\int_a^b \frac{q}{4\pi\varepsilon_0 K r^2} \cdot dr - \int_b^c \frac{q}{4\pi\varepsilon_0 r^2} dr$$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{K}\left(\frac{1}{a} - \frac{1}{b}\right) + \left(\frac{1}{b} - \frac{1}{c}\right)\right] = \frac{q}{4\pi\varepsilon_0}\left[\frac{(b-a)}{Kab} + \frac{(c-b)}{bc}\right]$$

$$= \frac{q}{4\pi\varepsilon_0 Kabc}[c(b-a) + Ka(c-b)]$$

$\therefore$ The desired capacitance is,

$$C = \frac{q}{V} = \frac{4\pi\varepsilon_0 Kabc}{Ka(c-b) + c(b-a)}$$ **Ans.**

Example 6 *A spherical capacitor is made of two conducting spherical shells of radii a and c. The space between the shells is filled with a dielectric of dielectric constant K upto a radius b as shown in figure. Find the capacitance of the system.*

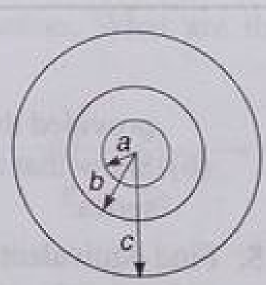


Fig. 22.127

HOW TO PROCEED *Here, the points are not mentioned between which the capacitance is asked. So, the capacitance will be calculated between the points, upto where the electric field extends. Hence, this is similar to the above example, because when we supply a charge q to inner shell and −q to outer shell, electric field exists between these two shells only.*

Solution Proceeding in the similar manner, we can find the capacitance of the system, which is equal to,

$$C = \frac{4\pi\varepsilon_0 Kabc}{Ka(c-b) + c(b-a)}$$ **Ans.**

EXERCISES

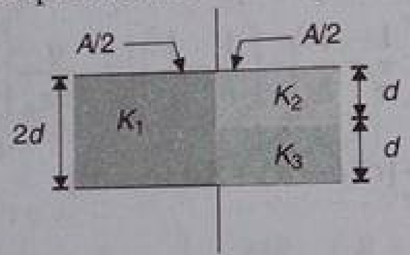
AIEEE Corner

Subjective Questions (Level 1)

Note *You can take approximations in the answers.*

Equivalent Capacitance

1. A parallel-plate capacitor has capacitance of 1.0 F. If the plates are 1.0 mm apart, what is the area of the plates?
2. Two parallel-plate vacuum capacitors have areas A_1 and A_2 and equal plate spacing d. Show that when the capacitors are connected in parallel, the equivalent capacitance is the same as for a single capacitor with plate area $A_1 + A_2$ and spacing d.
3. What is the capacitance of the capacitor, shown in figure?



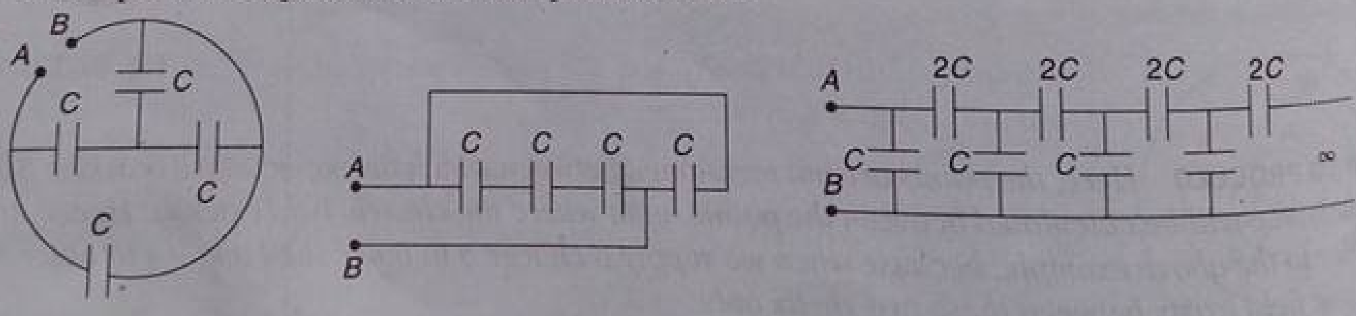
4. (a) Two spheres have radii a and b and their centres are at a distance d apart. Show that the capacitance of this system is;

$$C = \frac{4\pi\varepsilon_0}{\frac{1}{a} + \frac{1}{b} + \frac{2}{d}}$$

provided that d is large compared with a and b.

(b) Show that as d approaches infinity the above result reduces to that of two isolated spheres in series.

5. Find equivalent capacitance between points A and B



(a) (b) (c)

General Problems on Capacitors

6. A capacitor has a capacitance of 7.28 μF. What amount of charge must be placed on each of its plates to make the potential difference between its plates equal to 25.0 V ?

7. A parallel-plate air capacitor of capacitance 245 pF has a charge of magnitude 0.148 μC on each plate. The plates are 0.328 mm apart
   (a) What is the potential difference between the plates?
   (b) What is the area of each plate?
   (c) What is the surface charge density on each plate?
8. Two parallel plates have equal and opposite charges. When the space between the plates is evacuated, the electric field is $E = 3.20 \times 10^5$ V/m. When the space is filled with dielectric, the electric field is $E = 2.50 \times 10^5$ V/m.
   (a) What is the dielectric constant?
   (b) What is the charge density on each surface of the dielectric?
9. A 4.00 μF capacitor and a 6.00 μF capacitor are connected in parallel across a 660 V supply line.
   (a) Find the charge on each capacitor and the voltage across each.
   (b) The charged capacitors are disconnected from the line and from each other, and then reconnected to each other with terminals of unlike sign together. Find the final charge on each and the voltage across each.
10. A 5.80 μF parallel-plate air capacitor has a plate separation of 5.00 mm and is charged to a potential difference of 400 V. Calculate the energy density in the region between the plates, in J/m^3.
11. The dielectric to be used in a parallel-plate capacitor has a dielectric constant of 3.60 and a dielectric strength of 1.60×10^7 V/m. The capacitor is to have a capacitance of 1.25×10^{-9} F and must be able to withstand a maximum potential difference of 5500 V. What is the minimum area the plates of the capacitor may have?
12. Two condensers are in parallel and the energy of the combination is 0.1 J, when the difference of potential between terminals is 2 V. With the same two condensers in series, the energy is 1.6×10^{-2} J for the same difference of potential across the series combination. What are the capacities?
13. A circuit has section *AB* as shown in figure. The emf of the source equals $E = 10$ V, the capacitor capacitances are equal to $C_1 = 1.0\,\mu$F and $C_2 = 2.0\,\mu$F, and the potential difference $V_A - V_B = 5.0$ V. Find the voltage across each capacitor.

14. Several 10 pF capacitors are given, each capable of withstanding 100 V. How would you construct :
   (a) a unit possessing a capacitance of 2 pF and capable of withstanding 500 V?
   (b) a unit possessing a capacitance of 20 pF and capable of withstanding 300 V?
15. Two, capacitors *A* and *B* are connected in series across a 100 V supply and it is observed that the potential difference across them are 60 V and 40 V. A capacitor of 2 μF capacitance is now connected in parallel with *A* and the potential difference across *B* rises to 90 V. Determine the capacitance of *A* and *B*.
16. A 10.0 μF parallel-plate capacitor with circular plates is connected to a 12.0 V battery.
   (a) What is the charge on each plate?

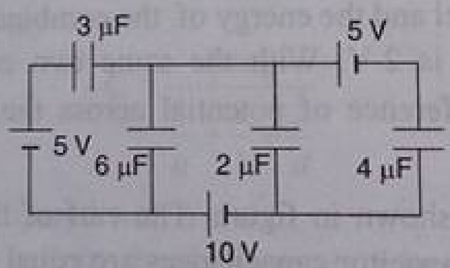
(b) How much charge would be on the plates if their separation were doubled while the capacitor remained connected to the battery?
(c) How much charge would be on the plates if the capacitor were connected to the 12.0 V battery after the radius of each plate was doubled without changing their separation?

17. A 450 μF capacitor is charged to 295 V. Then a wire is connected between the plates. How many joule of thermal energy are produced as the capacitor discharges if all of the energy that was stored goes into heating the wire?

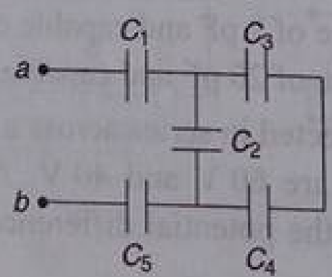
18. The plates of a parallel-plate capacitor in vacuum are 5.00 mm apart and 2.00 m^2 in area. A potential difference of 10,000 V is applied across the capacitor. Compute
(a) the capacitance
(b) the charge on each plate, and
(c) the magnitude of the electric field in the space between them.

19. Three capacitors having capacitances of 8.4 μF, 8.2 μF and 4.2 μF are connected in series across a 36 V potential difference.
(a) What is the charge on 4.2 μF capacitor?
(b) What is the total energy stored in all three capacitors?
(c) The capacitors are disconnected from the potential difference without allowing them to discharge. They are then reconnected in parallel with each other, with the positively charged plates connected together. What is the voltage across each capacitor in the parallel combination?
(d) What is the total energy now stored in the capacitors?

20. Find the charges on 6 μF and 4 μF capacitors.



21. In figure, $C_1 = C_5 = 8.4\,\mu F$ and $C_2 = C_3 = C_4 = 4.2\,\mu F$. The applied potential is $V_{ab} = 220$ V.
(a) What is the equivalent capacitance of the network between points a and b?
(b) Calculate the charge on each capacitor and the potential difference across each capacitor.

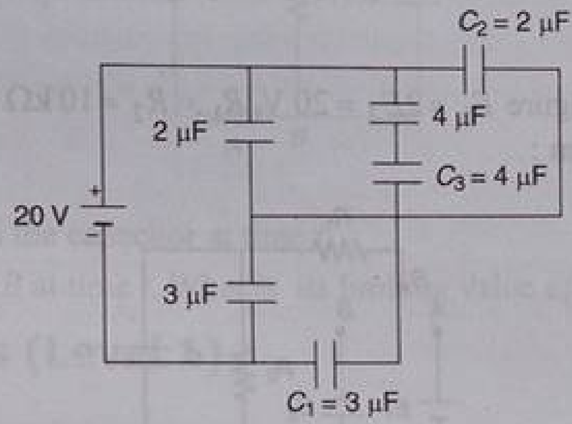


22. Two condensers A and B each having slabs of dielectric constant $K = 2$ are connected in series. When they are connected across 230 V supply, potential across A is 130 V and that across B is

100 V. If the dielectric in the condenser of smaller capacitance is replaced by one for which $K = 5$, what will be the values of potential difference across them.

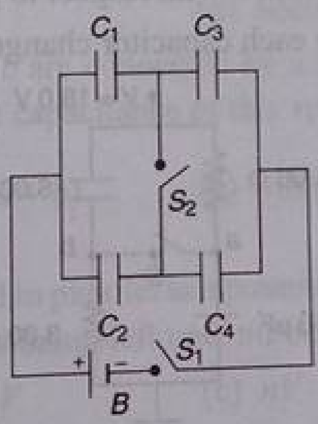
23. A capacitor of capacitance $C_1 = 1.0\ \mu F$ charged upto a voltage $V = 110$ V is connected in parallel to the terminals of a circuit consisting of two uncharged capacitors connected in series and possessing the capacitance $C_2 = 2.0\ \mu F$ and $C_3 = 3.0\ \mu F$. What charge will flow through the connecting wires?

24. In figure, the battery has a potential difference of 20 V. Find :



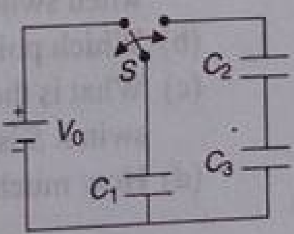
(a) the equivalent capacitance of all the capacitors across the battery and
(b) the charge stored on that equivalent capacitance. Find the charge on
(c) capacitor 1,
(d) capacitor 2, and
(e) capacitor 3.

25. In figure, battery B supplies 12 V. Find the charge on each capacitor



(a) first when only switch S_1 is closed and
(b) later when S_2 is also closed. (Take $C_1 = 1.0\ \mu F$, $C_2 = 2.0\ \mu F$, $C_3 = 3.0\ \mu F$ and $C_4 = 4.0\ \mu F$)

26. When switch S is thrown to the left in figure, the plates of capacitor 1 acquire a potential difference V_0. Capacitors 2 and 3 are initially uncharged. The switch is now thrown to the right. What are the final charges q_1, q_2 and q_3 on the capacitors?



27. A parallel-plate capacitor has plates of area A and separation d and is charged to a potential difference V. The charging battery is then disconnected, and the plates are pulled apart until their separation is $2d$. Derive expression in terms of A, d and V for

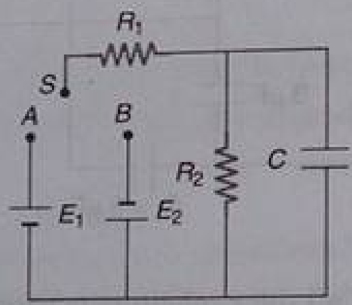
(a) the new potential difference

(b) the initial and final stored energies, U_i and U_f and

(c) the work required to increase the separation of plates from d to $2d$.

C-R Circuits

28. In the circuit shown in figure $E_1 = 2E_2 = 20$ V, $R_1 = R_2 = 10$ kΩ and $C = 1\,\mu$F. Find the current through R_1, R_2 and C when :



(a) S has been kept connected to A for a long time.

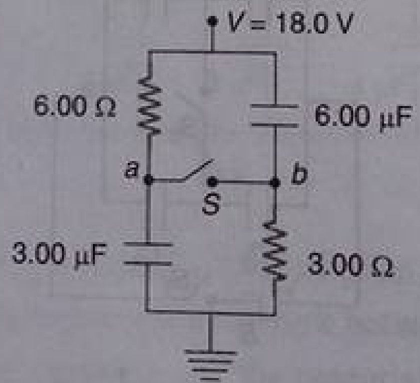
(b) The switch is suddenly shifted to B.

29. (a) What is the steady state potential of point a with respect to point b in figure when switch S is open?

(b) Which point, a or b, is at the higher potential?

(c) What is the final potential of point b with respect to ground when switch S is closed?

(d) How much does the charge on each capacitor change when S is closed?

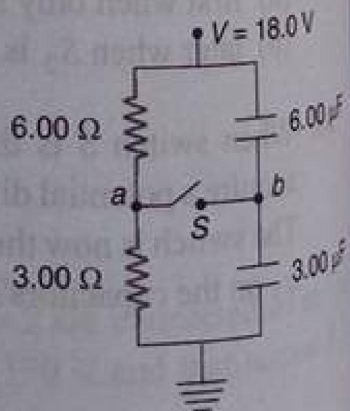


30. (a) What is the potential of point a with respect to point b in figure, when switch S is open?

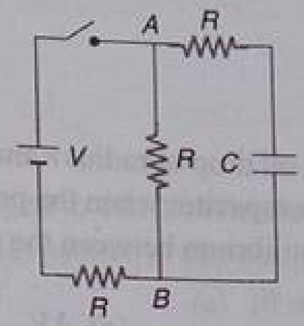
(b) Which point, a or b, is at the higher potential?

(c) What is the final potential of point b with respect to ground when switch S is closed?

(d) How much charge flows through switch S when it is closed?



31. In the circuit shown in figure, the battery is an ideal one with emf V. The capacitor is initially uncharged. The switch S is closed at time $t = 0$.



(a) Find the charge Q on the capacitor at time t.

(b) Find the current in AB at time t. What is its limiting value as $t \to \infty$?

Objective Questions (Level 1)

Single Correct Option

1. The separation between the plates of a charged parallel plate capacitor is increased. The force between the plates

   (a) increases (b) decreases

   (c) remains same (d) first increases then decreases

2. If the plates of a capacitor are joined together by a conducting wire, then its capacitance

   (a) remains unchanged (b) decreases

   (c) become zero (d) becomes infinite

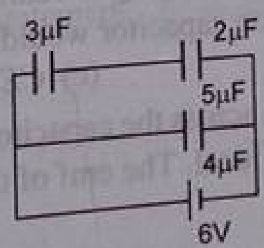
3. Two metal spheres of radii a and b are connected by a thin wire. Their separation is very large compared to their dimensions. The capacitance of this system is

   (a) $4\pi\varepsilon_0(ab)$ (b) $2\pi\varepsilon_0(a+b)$ (c) $4\pi\varepsilon_0(a+b)$ (d) $4\pi\varepsilon_0\left(\frac{a^2+b^2}{2}\right)$

4. n identical capacitors are connected in parallel to a potential difference V. These capacitors are then reconnected in series, their charges being left undisturbed. The potential difference obtained is

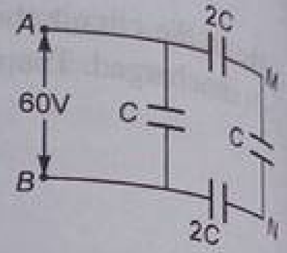
   (a) zero (b) $(n-1)V$ (c) nV (d) n^2V

5. In the circuit shown in figure the ratio of charge on 5 μF and 4 μF capacitor is



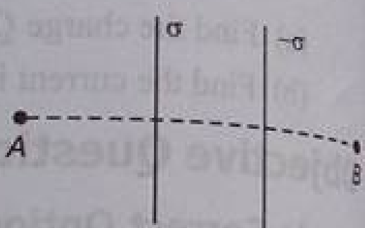
   (a) 4/5 (b) 3/5 (c) 3/8 (d) 1/2

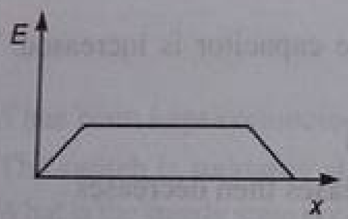
6. In the circuit shown a potential difference of 60 V is applied across AB. The potential difference between the points M and N is
(a) 10 V
(b) 15 V
(c) 20 V
(d) 30 V

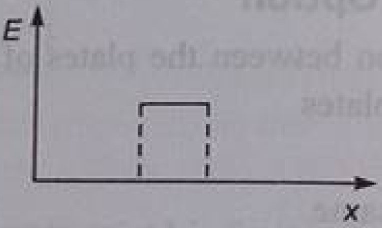


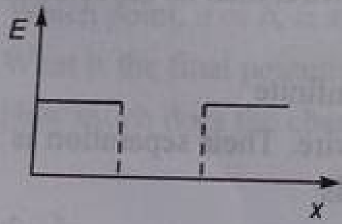
7. In Milikan's oil drop experiment an oil drop of radius r and charge q is held in equilibrium between the plates of a charged parallel plate capacitor when the potential difference is V. To keep a drop of radius $2r$ and with a charge $2q$ in equilibrium between the plates the potential difference V required is
(a) V (b) $2V$ (c) $4V$ (d) $8V$

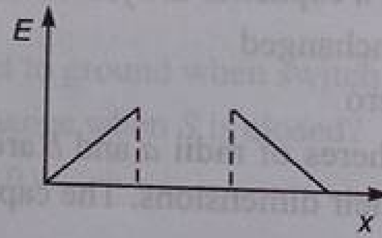
8. Two large parallel sheets charged uniformly with surface charge density σ and $-\sigma$ are located as shown in the figure. Which one of the following graphs shows the variation of electric field along a line perpendicular to the sheets as one moves from A to B?



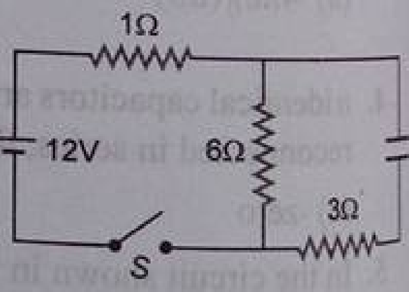
(a)


(b)


(c)


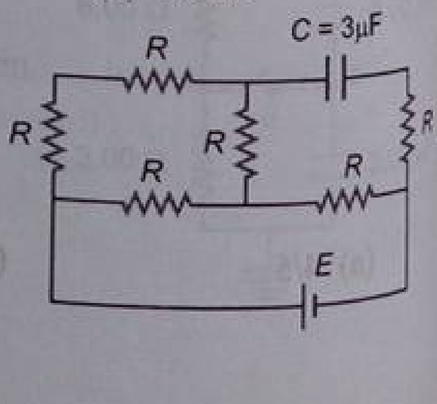
(d)


9. When the switch is closed, the initial current through the $1\,\Omega$ resistor is
(a) 2 A
(b) 4 A
(c) 3 A
(d) 6 A

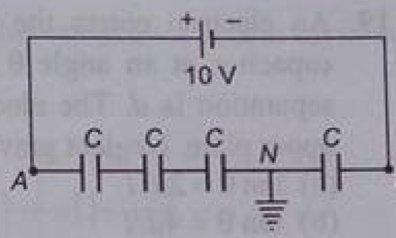


10. A capacitor of capacitance C carrying charge Q is connected to a source of emf E. Finally the charge on capacitor would be
(a) Q (b) $Q + CE$ (c) CE (d) None

11. In the circuit, the potential difference across the capacitor is 10 V. Each resistance is of $3\,\Omega$. The cell is ideal. The emf of the cell is
(a) 14 V
(b) 16 V
(c) 18 V
(d) 24 V



12. Four identical capacitors are connected in series with a 10 V battery as shown in the figure. The point N is earthed. The potentials of points A and B are



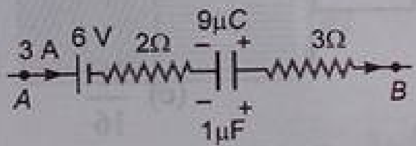
(a) 10 V, 0 V
(b) 7.5 V, – 2.5 V
(c) 5 V, – 5 V
(d) 7.5 V, 2.5 V

13. A capacitor of capacity 2 μF is charged to 100 V. What is the heat generated when this capacitor is connected in parallel to an another capacitor of same capacity?
(a) 2.5 mJ (b) 5.0 mJ (c) 10 mJ (d) 4 mJ

14. A charged capacitor is discharged through a resistance. The time constant of the circuit is η. Then the value of time constant for the power dissipated through the resistance will be
(a) η (b) 2η (c) η/2 (d) zero

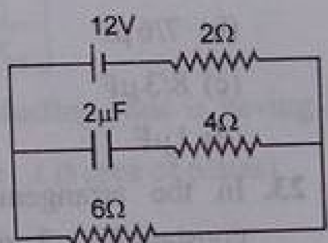
15. A capacitor is charged by a cell of emf E and the charging battery is then removed. If an identical capacitor is now inserted in the circuit in parallel with the previous capacitor, the potential difference across the new capacitor is
(a) $2E$ (b) E (c) $E/2$ (d) zero

16. The potential difference $V_A - V_B$ between points A and B for the circuit segment shown in figure at the given instant is



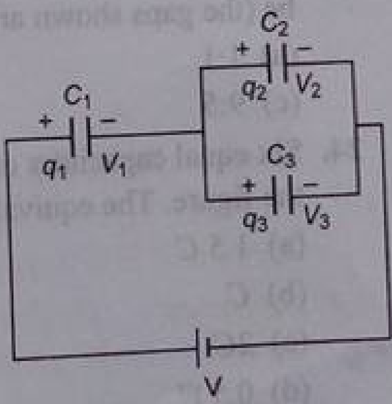
(a) 12 V (b) – 12 V (c) 6 V (d) – 6 V

17. For the circuit arrangement shown in figure, in the steady state condition charge on the capacitor is



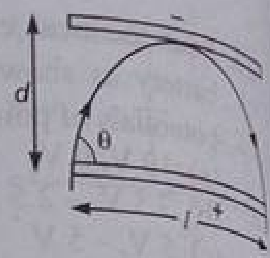
(a) 12 μC
(b) 14 μC
(c) 20 μC
(d) 18 μC

18. In the circuit as shown in figure if all the symbols have their usual meanings, then identify the correct statement



(a) $q_2 = q_3; V_2 = V_3$
(b) $q_1 = q_2 + q_3; V_2 = V_3$
(c) $q_1 = q_2 + q_3; V = V_1 + V_2 + V_3$
(d) $q_1 + q_2 + q_3 = 0; V_2 = V_3 = V - V_1$

19. An electron enters the region between the plates of a parallel plate capacitor at an angle θ to the plates. The plate width is l. The plate separation is d. The electron follows the path shown, just missing the upper plate. Neglect gravity. Then



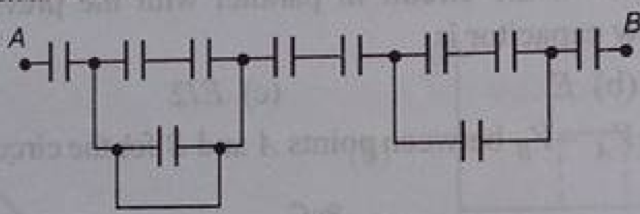
(a) $\tan\theta = 2d/l$
(b) $\tan\theta = 4d/l$
(c) $\tan\theta = 8d/l$
(d) The data given is insufficient to find a relation between d, l and θ

20. An infinite sheet of charge has a surface charge density of $10^{-7}\,C/m^2$. The separation between two equipotential surfaces whose potentials differ by 5 V is

(a) 0.64 cm (b) 0.88 mm (c) 0.32 cm (d) 5×10^{-7} m

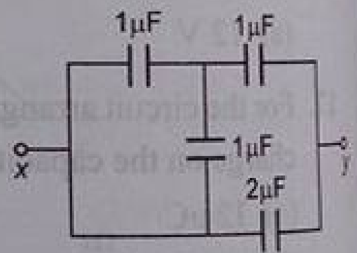
Equivalent Value of Capacitance

21. Find the equivalent capacitance across A and B for the arrangement shown in figure. All the capacitors are of capacitance C



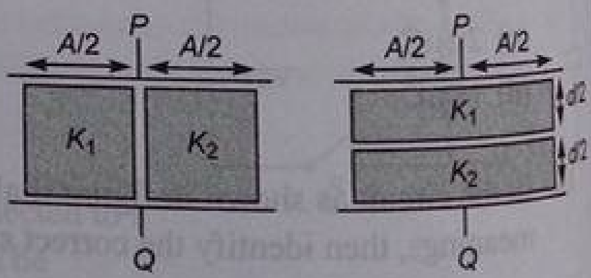
(a) $\frac{3C}{14}$ (b) $\frac{C}{8}$ (c) $\frac{3C}{16}$ (d) None of these

22. The equivalent capacitance between x and y is



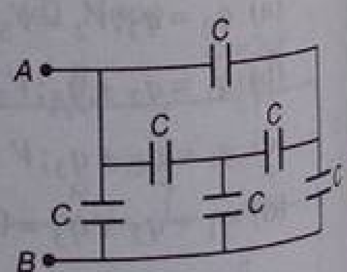
(a) $5/6\,\mu F$
(b) $7/6\,\mu F$
(c) $8/3\,\mu F$
(d) $1\,\mu F$

23. In the arrangement shown in figure, dielectric constant $K_1 = 2$ and $K_2 = 3$. If the capacitance across P and Q are C_1 and C_2 respectively, then C_1/C_2 will be (the gaps shown are negligible)



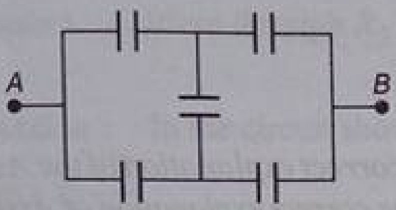
(a) 1:1 (b) 2:3
(c) 9:5 (d) 25:24

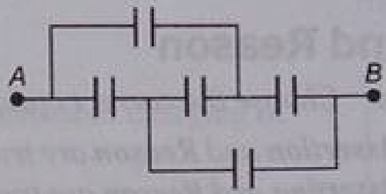
24. Six equal capacitors each of capacitance C are connected as shown in the figure. The equivalent capacitance between points A and B, is

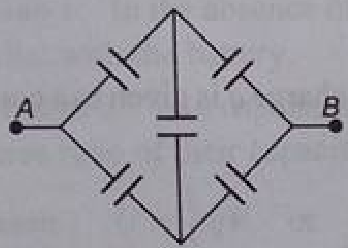


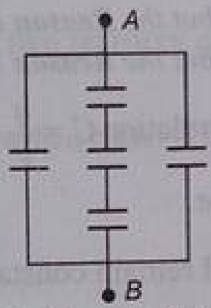
(a) 1.5 C
(b) C
(c) 2C
(d) 0.5 C

25. Four ways of making a network of five capacitors of the same value are shown in four choices. Three out of four are identical. The one which is different is

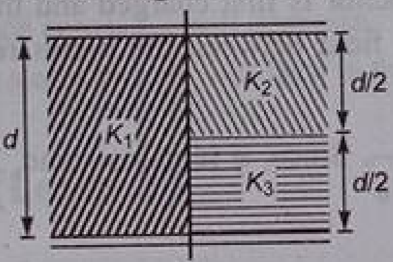
(a) 

(b) 

(c) 

(d) 

26. The equivalent capacitance of the arrangement shown in figure, if A is the area of each plate, is



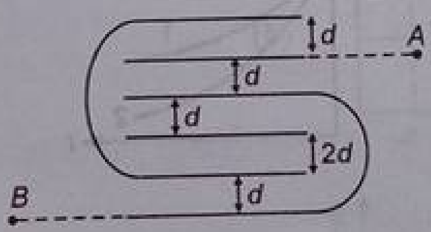
(a) $C = \dfrac{\varepsilon_0 A}{d}\left[\dfrac{K_1}{2} + \dfrac{K_2 + K_3}{K_2 K_3}\right]$

(b) $C = \dfrac{\varepsilon_0 A}{d}\left[\dfrac{K_1}{2} + \dfrac{K_2 K_3}{K_2 + K_3}\right]$

(c) $C = \dfrac{\varepsilon_0 A}{2d}\left[K_1 + \dfrac{K_2 K_3}{K_2 + K_3}\right]$

(d) $C = \dfrac{\varepsilon_0 A}{d}\left[K_1 + \dfrac{K_2 K_3}{K_2 + K_3}\right]$

27. Find equivalent capacitance between points A and B. [Assume each conducting plate is having same dimensions and neglect the thickness of the plate, $\dfrac{\varepsilon_0 A}{d} = 7\,\mu\text{F}$, where A is area of plates]



(a) $7\,\mu$F (b) $11\,\mu$F (c) $12\,\mu$F (d) $15\,\mu$F

JEE Corner

Assertion and Reason

Directions : *Choose the correct option.*

(a) *If both* ***Assertion*** *and* ***Reason*** *are true and the* ***Reason*** *is correct explanation of the* ***Assertion.***
(b) *If both* ***Assertion*** *and* ***Reason*** *are true but* ***Reason*** *is not the correct explanation of* ***Assertion.***
(c) *If* ***Assertion*** *is true, but the* ***Reason*** *is false.*
(d) *If* ***Assertion*** *is false but the* ***Reason*** *is true.*

1. **Assertion :** From the relation $C = \frac{q}{V}$. We can say that, if more charge q is given to a conductor, its capacity should increase.

   Reason : Ratio $\frac{q}{V}$ will remain constant for a given conductor.

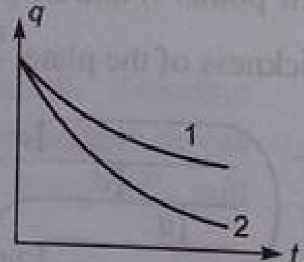
2. **Assertion :** A parallel plate capacitor is first charged and then distance between the plates is increased. In this process electric field between the plates remains the same, while potential difference gets decreased.

   Reason : $E = \frac{q}{A\varepsilon_0}$ and $V = \frac{q}{Ad\varepsilon_0}$. Since, q remains same, E will remain same while V will decrease.

3. **Assertion :** When an uncharged capacitor is charged by a battery only 50% of the energy supplied by a battery is stored in the capacitor.

   Reason : Rest 50% is lost.

4. **Assertion :** Discharging graphs of two C-R circuits having the same value of C is shown in figure. From the graph we can say that $\tau_{C_1} > \tau_{C_2}$.

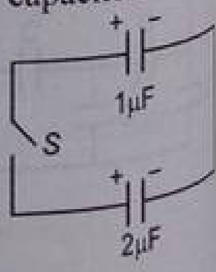


   Reason : $R_1 > R_2$.

5. **Assertion :** In series combination, charges on two capacitors are always equal.

   Reason : If charges are same, the total potential difference applied across two capacitors will be distributed in inverse ratio of capacities.

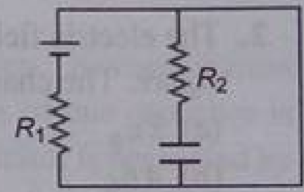
6. **Assertion :** Two capacitors are charged from the same battery and then connected as shown. A current will flow in anticlockwise direction, as soon as switch is closed.



   Reason : In steady state charges on two capacitors are in the ratio 1:2.

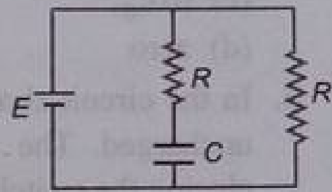
7. **Assertion :** In the circuit shown in figure, no charge will be stored in the capacitor.

Reason : Current through R_2 will be zero.



8. **Assertion :** In the circuit shown in figure, time constant of charging of battery is $\frac{CR}{2}$.

Reason : In the absence of capacitor in the circuit, two resistors are in parallel with the battery.

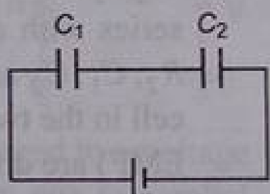


9. **Assertion :** Two capacitors are connected in series with a battery. Energy stored across them is in inverse ratio of their capacity.

Reason : $U = \frac{1}{2}qV$ or $U \propto qV$.

10. **Assertion :** In the circuit shown in figure, when a dielectric slab is inserted in C_2, the potential difference across C_2 will decrease.

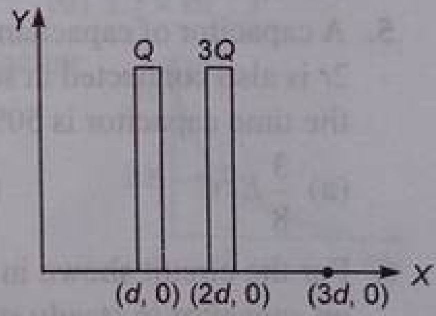
Reason : By inserting the slab a current will flow in the circuit in clockwise direction.

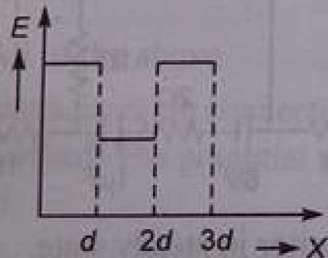


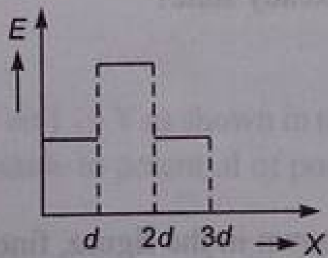
Objective Questions (Level 2)

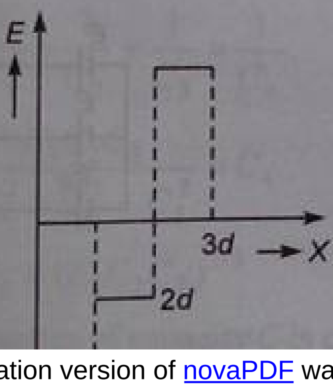
Single Correct Option

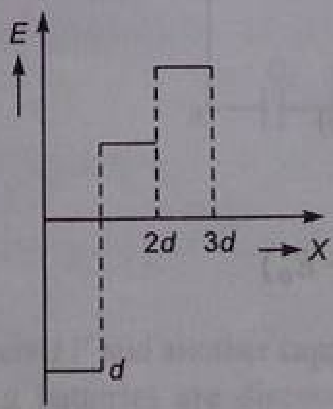
1. Two very large thin conducting plates having same cross-sectional area are placed as shown in figure. They are carrying charges Q and $3Q$ respectively. The variation of electric field as a function at x (for $x = 0$ to $x = 3d$) will be best represented by



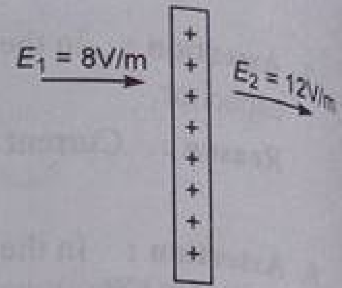
(a)


(b)


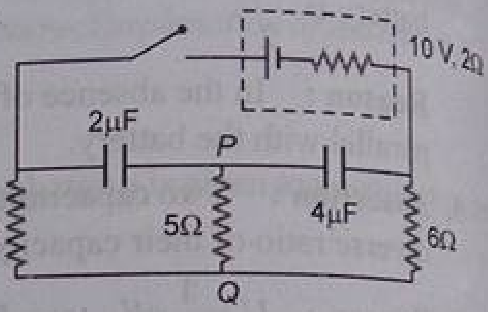
(c)


(d)


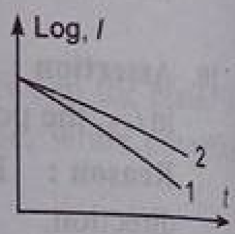
2. The electric field on two sides of a thin sheet of charge is shown in the figure. The charge density on the sheet is
(a) $2\varepsilon_0$
(b) $4\varepsilon_0$
(c) $10\varepsilon_0$
(d) zero



3. In the circuit shown in figure the capacitors are initially uncharged. The current through resistor PQ just after closing the switch is
(a) 2 A from P to Q
(b) 2 A from Q to P
(c) 6 A from P to Q
(d) zero



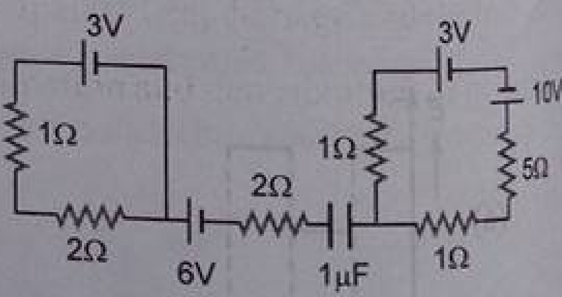
4. A graph between current and time during charging of a capacitor by a battery in series with a resistor is shown. The graphs are drawn for two circuits. R_1, R_2, C_1, C_2 and V_1, V_2 are the values of resistance, capacitance and EMF of the cell in the two circuits. If only two parameters (out of resistance, capacitance, EMF) are different in the two circuits. What may be the correct option(s)?



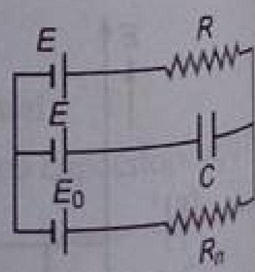
(a) $V_1 = V_2, R_1 > R_2, C_1 > C_2$
(b) $V_1 > V_2, R_1 > R_2, C_1 = C_2$
(c) $V_1 < V_2, R_1 < R_2, C_1 = C_2$
(d) $V_1 < V_2, R_1 = R_2, C_1 < C_2$

5. A capacitor of capacitance C is charged by a battery of emf E and internal resistance r. A resistance $2r$ is also connected in series with the capacitor. The amount of heat liberated inside the battery by the time capacitor is 50% charged is
(a) $\frac{3}{8}E^2C$ (b) $\frac{E^2C}{6}$ (c) $\frac{E^2C}{12}$ (d) $\frac{E^2C}{24}$

6. For the circuit shown in the figure, determine the charge on capacitor in steady state?
(a) 4 μC
(b) 6 μC
(c) 1 μC
(d) Zero



7. For the circuit shown in the figure, find the charge stored on capacitor in steady state
(a) $\frac{RC}{R+R_0}E$
(b) $\frac{RC}{R_0}(E-E_0)$
(c) zero
(d) $\frac{RC}{R+R_0}(E-E_0)$



8. Two similar parallel plate capacitors each of capacity C_0 are connected in series. The combination is connected with a voltage source of V_0. Now separation between the plates of one capacitor is increased by a distance d and the separation between the plates of another capacitor is decreased by the distance $d/2$. The distance between the plates of each capacitor was d before the change in separation. Then select the correct choice.

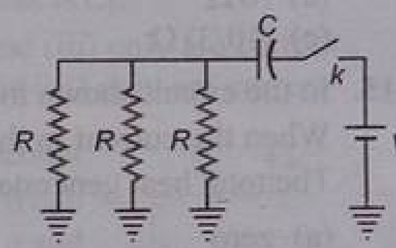
(a) The new capacity of the system will increase

(b) The new capacity of the system will decrease

(c) The new capacity of the system will remain same

(d) data insufficient

9. The switch shown in the figure is closed at $t = 0$. The charge on the capacitor as a function of time is given by



(a) $CV(1 - e^{-t/RC})$

(b) $3CV(1 - e^{-t/RC})$

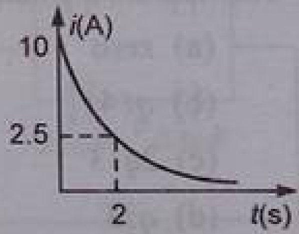
(c) $CV(1 - e^{-3t/RC})$

(d) $CV(1 - e^{-t/3RC})$

10. A 2 μF capacitor C_1 is charged to a voltage 100 V and a 4 μF capacitor C_2 is charged to a voltage 50 V. The capacitors are then connected in parallel. What is the loss of energy due to parallel connection?

(a) 1.7 J (b) 0.17 J (c) 1.7×10^{-2} J (d) 1.7×10^{-3} J

11. The figure shows a graph of the current in a discharging circuit of a capacitor through a resistor of resistance 10 Ω



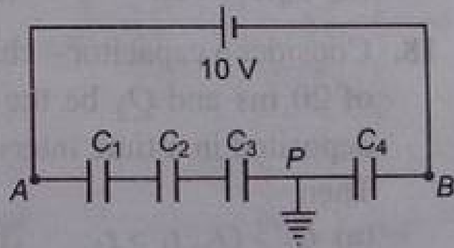
(a) The initial potential difference across the capacitor is 100 V

(b) The capacitance of the capacitor is $\frac{1}{10 \ln 2}$ F

(c) The total heat produced in the circuit will be $\frac{500}{\ln 2}$ J

(d) All of the above

12. Four capacitors are connected in series with a battery of emf 10 V as shown in the figure. The points P is earthed. The potential of point A is equal in magnitude to potential of point B but opposite in sign if



(a) $C_1 + C_2 + C_3 = C_4$

(b) $\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{C_4}$

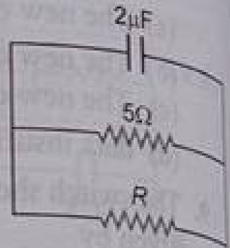
(c) $\frac{C_1 C_2 C_3}{C_1^2 + C_2^2 + C_3^2} = C_4$

(d) $C_4 = (C_1 C_2 C_3)^{1/3}$

13. A capacitor of capacity C is charged to a potential difference V and another capacitor of capacity $2C$ is charged to a potential difference $4V$. The charging batteries are disconnected and the two capacitors are connected with reverse polarity (*i.e.*, positive plate of first capacitor is connected to negative plate of second capacitor). The heat produced during the redistribution of charge between the capacitors will be

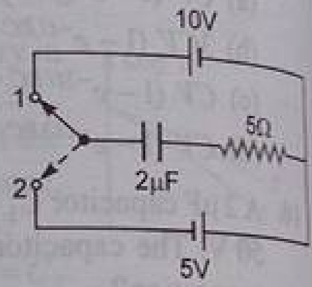
(a) $\frac{125CV^2}{3}$ (b) $\frac{50CV^2}{3}$ (c) $2CV^2$ (d) $\frac{25CV^2}{3}$

14. A capacitor of capacitance $2\,\mu F$ is charged to a potential difference of 5 V. Now the charging battery is disconnected and the capacitor is connected in parallel to a resistor of $5\,\Omega$ and another unknown resistor of resistance R as shown in figure. If the total heat produced in $5\,\Omega$ resistance is $10\,\mu J$ then the unknown resistance R is equal to



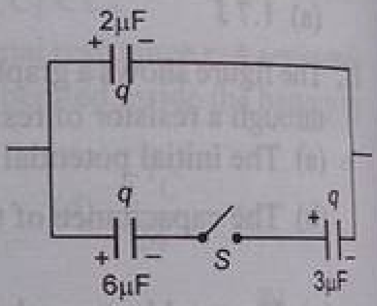
(a) $10\,\Omega$ (b) $15\,\Omega$
(c) $(10/3)\,\Omega$ (d) $7.5\,\Omega$

15. In the circuit shown in figure switch S is thrown to position 1 at $t = 0$. When the current in the resistor is 1 A it is then shifted to position 2. The total heat generated in the circuit after shifting to position 2 is



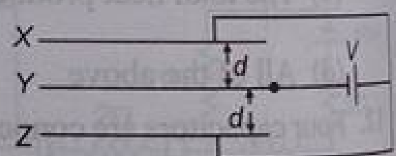
(a) zero
(b) $625\,\mu J$
(c) $100\,\mu J$
(d) None of the above

16. The flow of charge through switch if it is closed is



(a) zero
(b) $q/4$
(c) $2q/3$
(d) $q/3$

17. Consider the arrangement of three plates X, Y and Z each of the area A and separation d. The energy stored when the plates are fully charged is

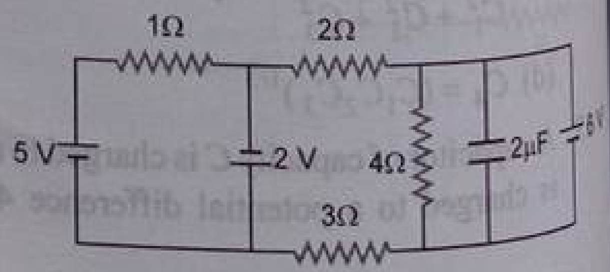


(a) $\varepsilon_0 AV^2/2d$ (b) $\varepsilon_0 AV^2/d$ (c) $2\varepsilon_0 AV^2/d$ (d) $3\varepsilon_0 AV^2/d$

18. Consider a capacitor – charging circuit. Let Q_1 be the charge given to the capacitor in time interval of 20 ms and Q_2 be the charge given in the next time interval of 20 ms. Let $10\,\mu C$ charge be deposited in a time interval t_1 and the next $10\,\mu C$ charge is deposited in the next time interval t_2. Then

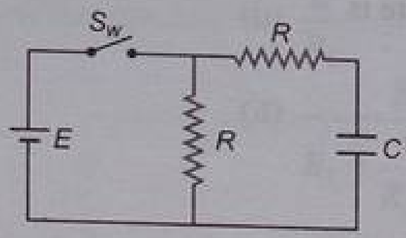
(a) $Q_1 > Q_2, t_1 > t_2$ (b) $Q_1 > Q_2, t_1 < t_2$ (c) $Q_1 < Q_2, t_1 > t_2$ (d) $Q_1 < Q_2, t_1 < t_2$

19. The current in $1\,\Omega$ resistance and charge stored in the capacitor are



(a) $4\text{ A}, 6\,\mu C$ (b) $7\text{ A}, 12\,\mu C$
(c) $4\text{ A}, 12\,\mu C$ (d) $7\text{ A}, 6\,\mu C$

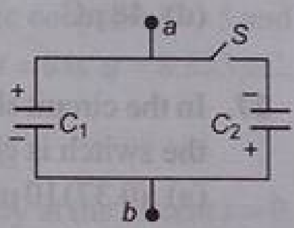
20. A capacitor C is connected to two equal resistances as shown in the figure. Consider the following statements



(i) At the time of charging of capacitor time constant of the circuit is $2CR$
(ii) At the time of discharging of the capacitor the time constant of the circuit is CR
(iii) At the time of discharging of the capacitor the time constant of the circuit is $2CR$
(iv) At the time of charging of capacitor the time constant of the circuit is CR

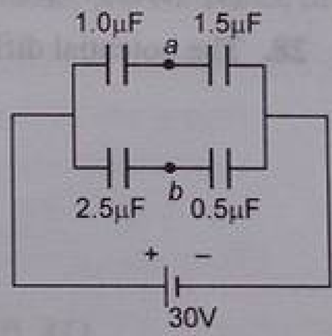
(a) Statements (i) and (ii) only are correct
(b) Statements (ii) and (iii) only are correct
(c) Statements (iii) and (iv) only are correct
(d) Statements (i) and (iii) only are correct

21. Two capacitors $C_1 = 1\,\mu F$ and $C_2 = 3\,\mu F$ each is charged to a potential difference of 100 V but with opposite polarity as shown in the figure. When the switch S is closed, the new potential difference between the points a and b is



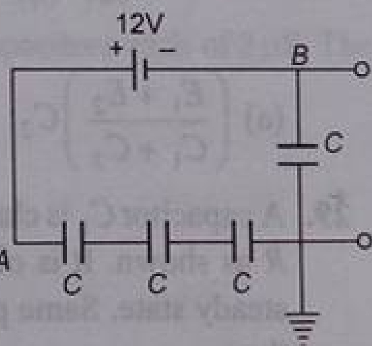
(a) 200 V
(b) 100 V
(c) 50 V
(d) 25 V

22. Four capacitors are connected as shown in figure to a 30 V battery. The potential difference between points a and b is



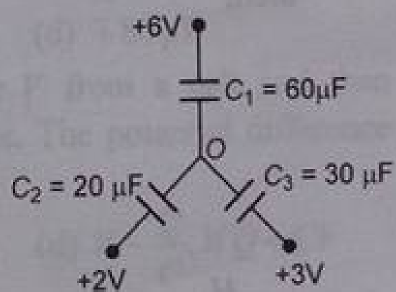
(a) 5 V
(b) 9 V
(c) 10 V
(d) 13 V

23. Four identical capacitors are connected in series with a 12 V battery as shown in figure. The potentials of points A and B are



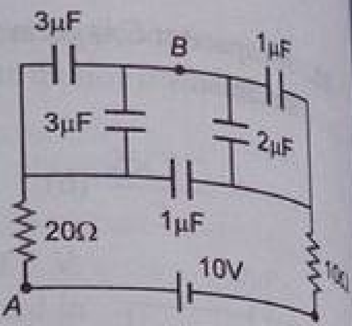
(a) + 10 V , 0 V
(b) + 9 V, − 3 V
(c) + 3 V, + 9 V
(d) + 12 V, − 3 V

24. Three uncharged capacitors of capacitance C_1, C_2 and C_3 are connected to one another as shown in figure. The potential at O will be



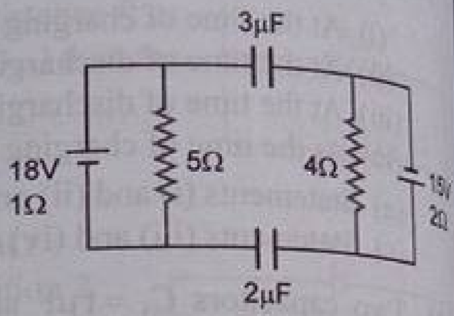
(a) 3 V
(b) $\frac{49}{11}$ V
(c) 4 V
(d) $\frac{3}{11}$ V

25. In the circuit, shown in figure, the potential difference between the points A and B in the steady state is



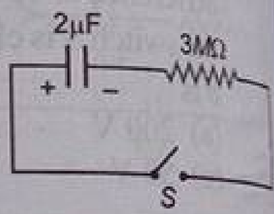
(a) zero
(b) 6 V
(c) 4 V
(d) $\frac{10}{3}$ V

26. Two cells, two resistors and two capacitors are connected as shown in figure. The charge on 2 μF capacitor is



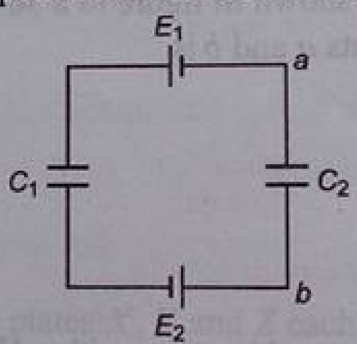
(a) 30 μC
(b) 20 μC
(c) 25 μC
(d) 48 μC

27. In the circuit shown in figure the capacitor is charged with a cell of 5 V. If the switch is closed at $t=0$, then at $t=12$ s, charge on the capacitor is



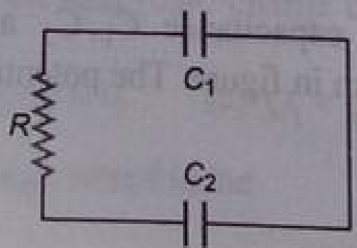
(a) $(0.37)10\,\mu C$ (b) $(0.37)^2 10\,\mu C$
(c) $(0.63)10\,\mu C$ (d) $(0.63)^2 10\,\mu C$

28. The potential difference between points a and b of circuits shown in the figure is



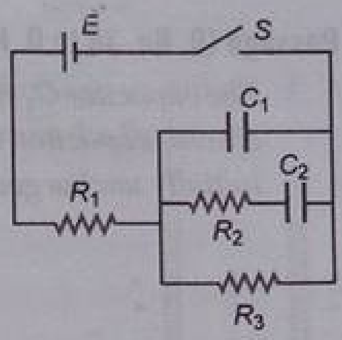
(a) $\left(\frac{E_1+E_2}{C_1+C_2}\right)C_2$ (b) $\left(\frac{E_1-E_2}{C_1+C_2}\right)C_2$ (c) $\left(\frac{E_1+E_2}{C_1+C_2}\right)C_1$ (d) $\left(\frac{E_1-E_2}{C_1+C_2}\right)C_1$

29. A capacitor C_1 is charged to a potential V and connected to another capacitor in series with a resistor R as shown. It is observed that heat H_1 is dissipated across resistance R, till the circuit reaches steady state. Same process is repeated using resistance of $2R$. If H_2 is heat dissipated in this case then,



(a) $\frac{H_2}{H_1}=1$ (b) $\frac{H_2}{H_1}=4$ (c) $\frac{H_2}{H_1}=\frac{1}{4}$ (d) $\frac{H_2}{H_1}=2$

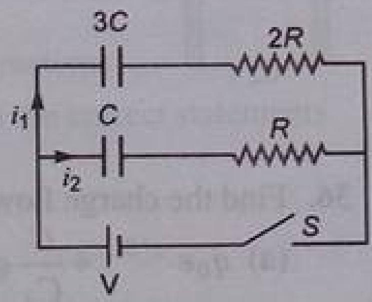
30. In the circuit diagram, the current through the battery immediately after the switch S is closed is



(a) zero (b) $\frac{E}{R_1}$

(c) $\frac{E}{R_1 + R_2}$ (d) $\frac{E}{R_1 + \frac{R_2 R_3}{R_2 + R_3}}$

31. In the circuit shown, switch S is closed at $t = 0$. Let i_1 and i_2 be the current at any finite time t, then the ratio i_1 / i_2

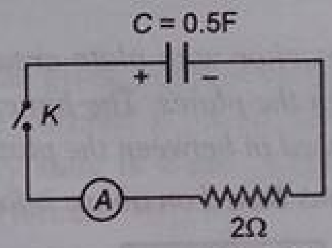


(a) is constant
(b) increases with time
(c) decreases with time
(d) first increases and then decreases

32. A leaky parallel capacitor is filled completely with a material having dielectric constant $K = 5$ and electrical conductivity $\sigma = 7.4 \times 10^{-12} \Omega^{-1} m^{-1}$. Charge on the plate at instant $t = 0$ is $q = 8.885 \mu C$. Then time constant of leaky capacitor is

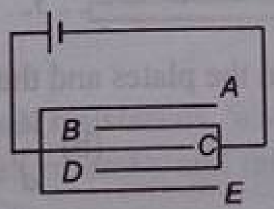
(a) 3 s (b) 4 s (c) 5 s (d) 6 s

33. A charged capacitor is allowed to discharge through a resistor by closing the key at the instant $t = 0$. At the instant $t = (\ln 4)\ \mu s$, the reading of the ammeter falls half the initial value. The resistance of the ammeter is equal to



(a) 0.5Ω (b) 1Ω (c) 2Ω (d) 4Ω

34. Five identical capacitor plates are arranged such that they make four capacitors each of $2 \mu F$. The plates are connected to a source of emf 10 V. The charge on plate C is



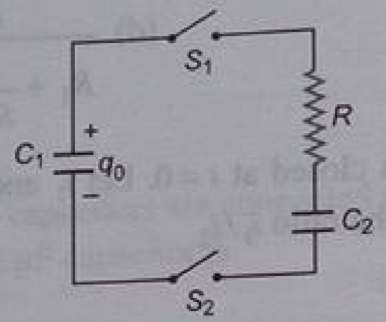
(a) $+20 \mu F$ (b) $+40 \mu F$ (c) $+60 \mu F$ (d) $+80 \mu F$

35. A capacitor of capacitance C is charged to a potential difference V from a cell and then disconnected from it. A charge $+Q$ is now given to its positive plate. The potential difference across the capacitor is now

(a) V (b) $V + \frac{Q}{C}$ (c) $V + \frac{Q}{2C}$ (d) $V - \frac{Q}{C}$, if $Q < CV$

Passage (Q. No. 36 to Q. No. 37)

The capacitor C_1 in the figure shown initially carries a charge q_0. When the switches S_1 and S_2 are closed, capacitor C_1 is connected in series to a resistor R and a second capacitor C_2, which is initially uncharged.



36. Find the charge flown through wires as a function of time

(a) $q_0 e^{-t/RC} + \frac{C}{C_2} q_0$

(b) $\frac{q_0 C}{C_1} \times [1 - e^{-t/RC}]$

(c) $q_0 \frac{C}{C_1} e^{-t/CR}$

(d) $q_0 e^{-t/RC}$ where $C = \frac{C_1 C_2}{C_1 + C_2}$

37. Find the total heat dissipated in the circuit during the discharging process of C_1

(a) $\frac{q_0^2}{2C_1^2} \times C$

(b) $\frac{q_0^2}{2C}$

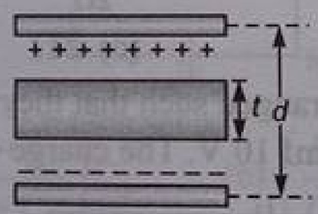
(c) $\frac{q_0^2 C_2}{2C_1^2}$

(d) $\frac{q_0^2}{2C_1 C_2}$

Passage (Q. No. 38 to Q. No. 39)

Figure shows a parallel plate capacitor with plate area A and plate separation d. A potential difference is being applied between the plates. The battery is then disconnected and a dielectric slab of dielectric constant K is placed in between the plates of the capacitor as shown.

Now, answer the following questions based on above information.



38. The electric field in the gaps between the plates and the dielectric slab will is

(a) $\frac{\varepsilon_0 AV}{d}$

(b) $\frac{V}{d}$

(c) $\frac{KV}{d}$

(d) $\frac{V}{d-t}$

39. The electric field in the dielectric slab is

(a) $\frac{V}{Kd}$

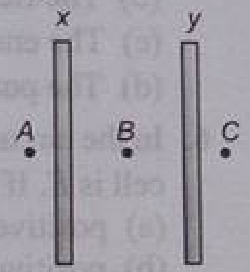
(b) $\frac{KV}{d}$

(c) $\frac{V}{d}$

(d) $\frac{KV}{t}$

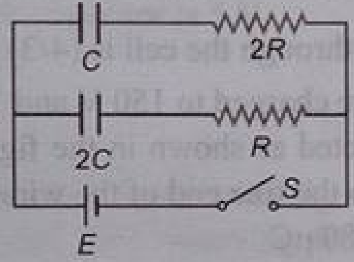
More than One Correct Options

1. X and Y are large, parallel conducting plates close to each other. Each face has an area A. X is given a charge Q. Y is without any charge. Points A, B and C are as shown in the figure



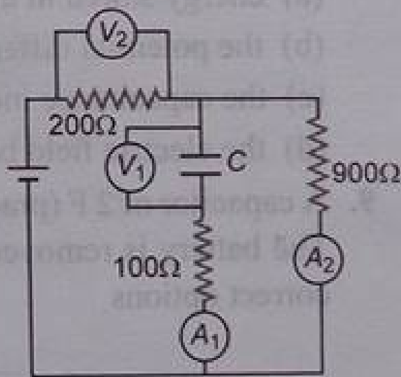
   (a) The field at B is $\frac{Q}{2\varepsilon_0 A}$
   (b) The field at B is $\frac{Q}{\varepsilon_0 A}$
   (c) The field at A, B and C are of the same magnitude
   (d) The fields at A and C are of the same magnitude, but in opposite directions

2. In the circuit shown in the figure, switch S is closed at time $t = 0$. Select the correct statements



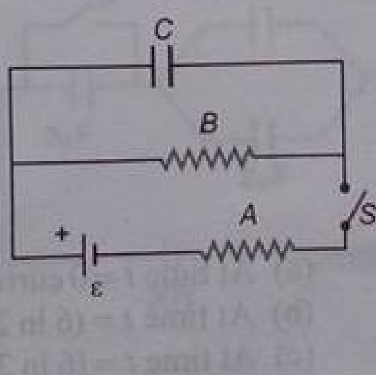
   (a) rate of increase of charge is same in both the capacitors
   (b) ratio of charge stored in capacitors C and $2C$ at any time t would be 1 : 2
   (c) time constants of both the capacitors are equal
   (d) steady state charge in capacitors C and $2C$ are in the ratio of 1 : 2

3. An electrical circuit is shown in the given figure. The resistance of each voltmeter is infinite and each ammeter is 100 Ω. The charge on the capacitor of 100 μF in steady state is 4 mC. Choose correct statements (s) regarding the given circuit



   (a) Reading of voltmeter V_2 is 16 V
   (b) Reading of ammeter A_1 is zero and A_2 is 1/25 A
   (c) Reading of voltmeter V_1 is 40 V
   (d) EMF of the ideal cell is 66 V

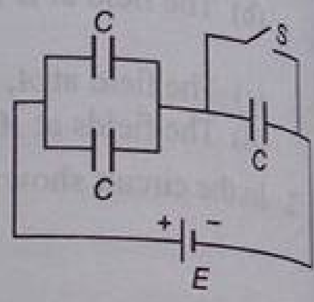
4. In the circuit shown, A and B are equal resistances. When S is closed, the capacitor C charges from the cell of emf ε and reaches a steady state



   (a) During charging, more heat is produced in A then in B
   (b) In steady state, heat is produced at the same rate in A and B
   (c) In the steady state, energy stored in C is $\frac{1}{4}C\varepsilon^2$
   (d) In the steady state energy stored in C is $\frac{1}{8}C\varepsilon^2$

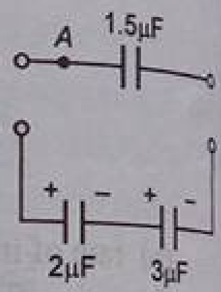
5. A parallel plate capacitor is charged from a cell and then isolated from it. The separation between the plates is now increased
(a) The force of attraction between the plates will decrease
(b) The field in the region between the plates will not change
(c) The energy stored in the capacitor will increase
(d) The potential difference between the plates will decrease

6. In the circuit shown, each capacitor has a capacitance C. The emf of the cell is E. If the switch S is closed



(a) positive charge will flow out of the positive terminal of the cell
(b) positive charge will enter the positive terminal of the cell
(c) the amount of the charge flowing through the cell will be $\frac{1}{3}CE$
(d) the amount of charge flowing through the cell is $(4/3)\,CE$

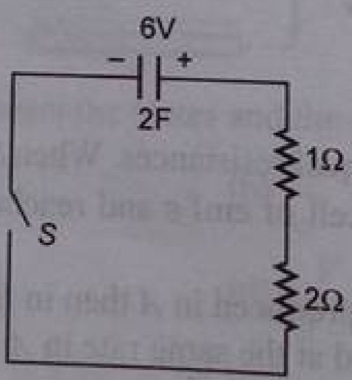
7. Two capacitors of $2\,\mu F$ and $3\,\mu F$ are charged to 150 V and 120 V respectively. The plates of capacitor are connected as shown in the figure. An uncharged capacitor of capacity $1.5\,\mu F$ falls to the free end of the wire. Then



(a) charge on $1.5\,\mu F$ capacitor is $180\,\mu C$
(b) charge on $2\,\mu F$ capacitor is $120\,\mu C$
(c) positive charge flows through A from right to left
(d) positive charge flows through A from left to right

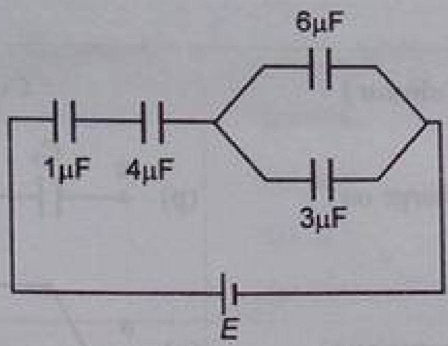
8. A parallel plate capacitor is charged and then the battery is disconnected. When the plates of the capacitor are brought closer, then
(a) energy stored in the capacitor decreases
(b) the potential difference between the plates decreases
(c) the capacitance increases
(d) the electric field between the plates decreases

9. A capacitor of 2 F (practically not possible to have a capacity of 2 F) is charged by a battery of 6 V. The battery is removed and circuit is made as shown. Switch is closed at time $t = 0$. Choose the correct options



(a) At time $t = 0$ current in the circuit is 2 A
(b) At time $t = (6 \ln 2)$ second potential difference across capacitor is 3 V
(c) At time $t = (6 \ln 2)$ second, potential difference across $1\,\Omega$ resistance is 1 V
(d) At time $t = (6 \ln 2)$ second potential difference across $2\,\Omega$ resistance is 2 V

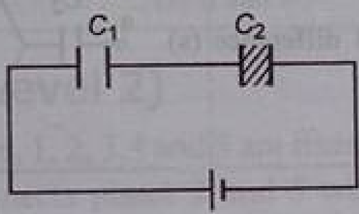
10. Given that potential difference across 1 μF capacitor is 10 V. Then



(a) potential difference across 4 μF capacitor is 40 V
(b) potential difference across 4 μF capacitor is 2.5 V
(c) potential difference across 3 μF capacitor is 5 V
(d) value of E is 70 V

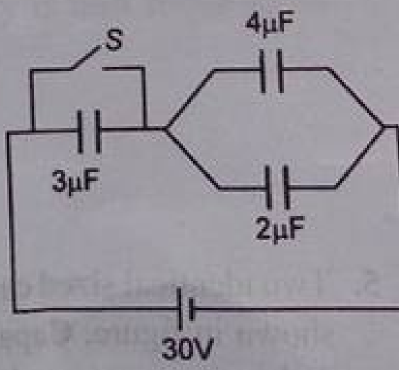
Match the Columns

1. In the figure shown $C_1 = 4\,\mu F$ (without dielectric) and $C_2 = 4\,\mu F$ (with a dielectric slab of dielectric constant $K = 2$). Now the same slab after removing from C_2 is filled in C_1. Then match the following two columns.



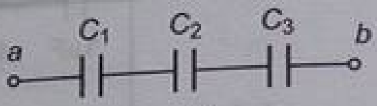
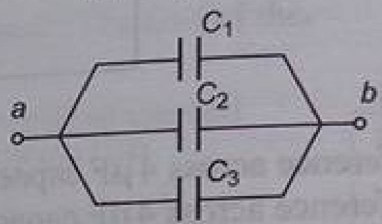
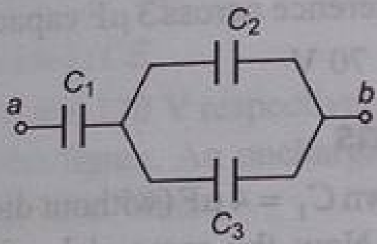
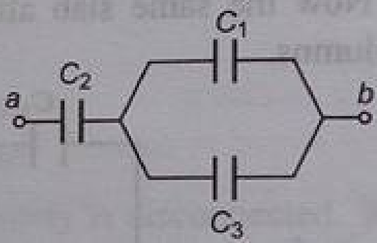
Column I	Column II
(a) Charge on C_2	(p) will increase
(b) Energy stored in C_2	(q) will decrease
(c) Potential difference across C_2	(r) will remain same
(d) Electric field between the plates of C_2	(s) data insufficient

2. In the circuit shown in figure, match the following two columns for flow of charge when switch is closed.



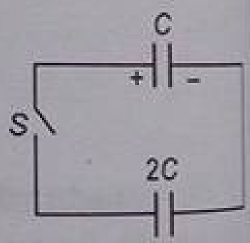
Column I	Column II
(a) From the battery	(p) 40 μC
(b) From 2 μF capacitor	(q) 100 μC
(c) From 3 μF	(r) 60 μC
(d) From 4 μF capacitor	(s) None of these

3. Three identical capacitors are connected in three different configurations as shown in column II. Match the two columns.

Column I	Column II
(a) Maximum charge on C_1	(p) 
(b) Minimum charge on C_2	(q) 
(c) Maximum potential difference across C_1	(r) 
(d) Minimum potential difference across C_1	(s) 

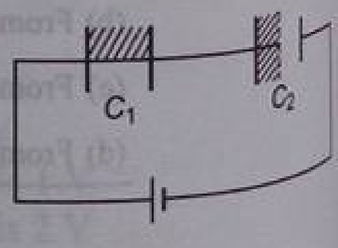
Note *In all cases* $V_{ab} = V$.

4. A capacitor C is charged by a battery of V volts. Then it is connected to an uncharged capacitor of capacity $2C$ as shown in figure. Now match the following two columns.



Column I	Column II
(a) After closing the switch energy stored in C.	(p) $\frac{1}{9}CV^2$
(b) After closing the switch energy stored in $2C$.	(q) $\frac{1}{6}CV^2$
(c) After closing the switch loss of energy during redistribution of charge.	(r) $\frac{1}{18}CV^2$
	(s) None of these

5. Two identical sized capacitors C_1 and C_2 are connected with a battery as shown in figure. Capacitor plates are square plates. A dielectric slab of dielectric constant $K = 2$, are filled in half the region of the two capacitors as shown :

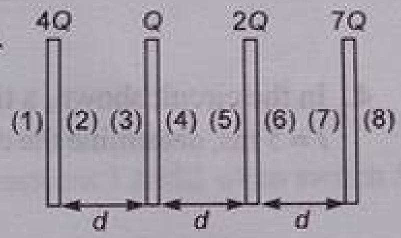


$C \rightarrow$ capacity, $q \rightarrow$ charge stored, $U \rightarrow$ energy stored.

Match the following two columns.

Column I	Column II
(a) C_1/C_2	(p) 9/4
(b) q_1/q_2	(q) 4/9
(c) U_1/U_2	(r) 4/3
	(s) None of these

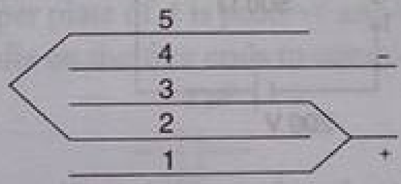
6. Four large parallel identical conducing plates are arranged as shown.



Column I	Column II
(a) Surfaces having charges of same magnitude and sign	(p) 1 and 8
(b) Surfaces having positive charges	(q) 3 and 5
(c) Uncharged surfaces	(r) 2 and 3
(d) Charged surfaces	(s) 6 and 7

Subjective Questions (Level 2)

1. Five identical conducting plates, 1, 2, 3,4 and 5 are fixed parallel plates equidistant from each other (see figure). A conductor connects plates 2 and 5 while another conductor joins 1 and 3. The junction of 1 and 3 and the plate 4 are connected to a source of constant emf V_0. Find :

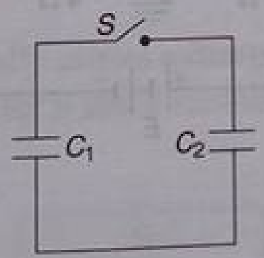


(a) The effective capacity of the system between the terminals of source.

(b) The charges on the plates 3 and 5.

Given, d = distance between any two successive plates and A = area of either face of each plate.

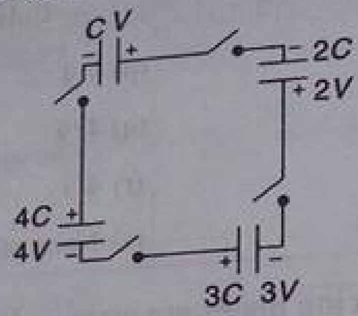
2. A 8 μF capacitor C_1 is charged to $V_0 = 120$ volt. The charging battery is then removed and the capacitor is connected in parallel to an uncharged +4 μF capacitor C_2.



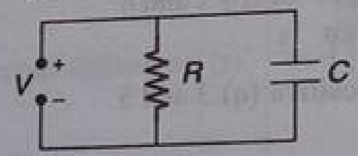
(a) What is the potential difference V across the combination?

(b) What is the stored energy before and after the switch S is closed?

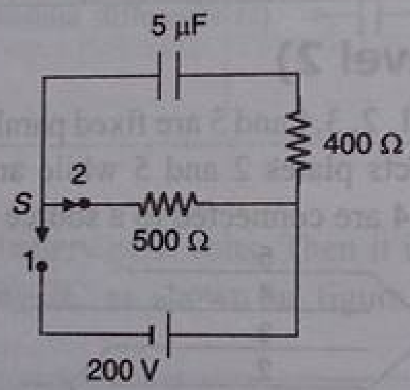
3. Condensers with capacities $C, 2C, 3C$ and $4C$ are charged to the voltage, $V, 2V, 3V$ and $4V$ correspondingly. The circuit is closed. Find the voltage on all condensers in the equilibrium.



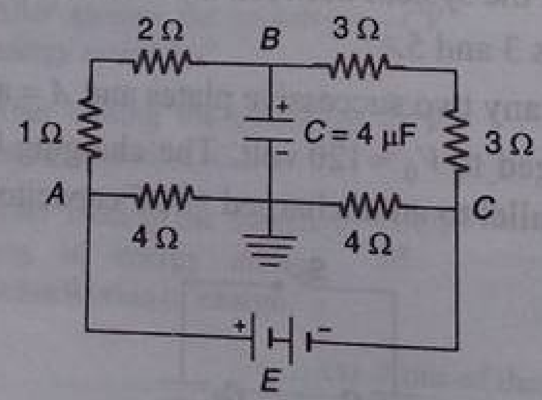
4. In the circuit shown, a time varying voltage $V = 2000t$ volt is applied where t is in second. At time $t = 5$ ms, determine the current through the resistor $R = 4\,\Omega$ and through the capacitor $C = 300\,\mu$F.



5. A capacitor of capacitance $5\,\mu$F is connected to a source of constant emf of 200 V. Then the switch was shifted to contact 2 from contact 1. Find the amount of heat generated in the $400\,\Omega$ resistance.



6. Analyse the given circuit in the steady state condition. Charge on the capacitor is $q_0 = 16\,\mu$C.

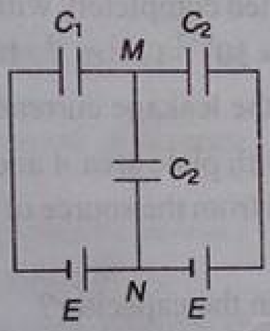


(a) Find the current in each branch

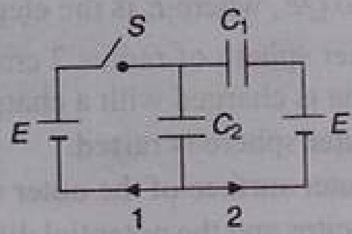
(b) Find the emf of the battery.

(c) If now the battery is removed and the points A and C are shorted. Find the time during which charge on the capacitor becomes $8\,\mu$C.

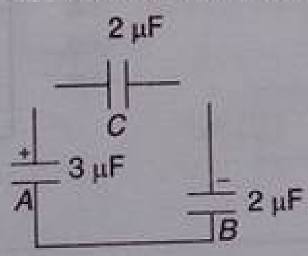
7. Find the potential difference between points M and N of the system shown in figure, if the emf is equal to $E = 110$ V and the capacitance ratio $\frac{C_1}{C_2}$ is 2.



8. In the given circuit diagram, find the charges which flow through directions 1 and 2 when switch S is closed.



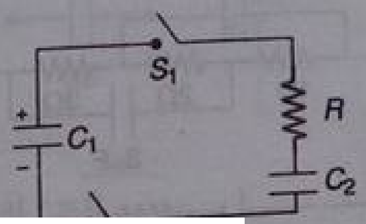
9. Two capacitors A and B with capacities $3\ \mu F$ and $2\ \mu F$ are charged to a potential difference of 100 V and 180 V respectively. The plates of the capacitors are connected as shown in figure with one wire of each capacitor free. The upper plate of A is positive and that of B is negative. An uncharged $2\ \mu F$ capacitor C with lead wires falls on the free ends to complete the circuit. Calculate



(i) the final charge on the three capacitors,

(ii) the amount of electrostatic energy stored in the system before and after completion of the circuit.

10. The capacitor C_1 in the figure initially carries a charge q_0. When the switch S_1 and S_2 are closed, capacitor C_1 is connected to a resistor R and a second capacitor C_2, which initially does not carry any charge.



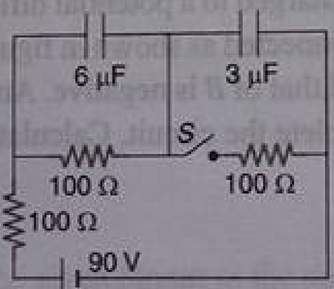
(a) Find the charges deposited on the capacitors in steady state and the current through R as a function of time.
(b) What is heat lost in the resistor after a long time of closing the switch.

11. A leaky parallel plate capacitor is filled completely with a material having dielectric constant $K = 5$ and electrical conductivity $\sigma = 7.4 \times 10^{-12}\ \Omega^{-1}\text{m}^{-1}$. If the charge on the capacitor at the instant $t = 0$ is $q_0 = 8.55\ \mu\text{C}$, then calculate the leakage current at the instant $t = 12$ s.

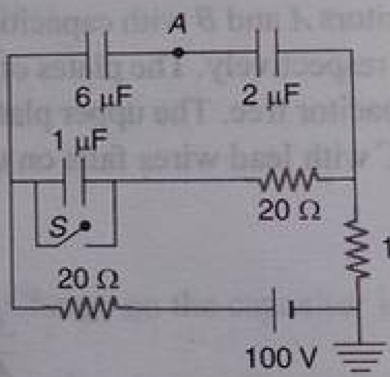
12. A parallel-plate vacuum capacitor with plate area A and separation x has charges $+Q$ and $-Q$ on its plates. The capacitor is disconnected from the source of charge, so the charge on each plate remains fixed.
(a) What is the total energy stored in the capacitor?
(b) The plates are pulled apart an additional distance dx. What is the change in the stored energy?
(c) If F is the force with which the plates attract each other, then the change in the stored energy must equal the work $dW = Fdx$ done in pulling the plates apart. Find an expression for F.
(d) Explain why F is not equal to QE, where E is the electric field between the plates.

13. A spherical capacitor has the inner sphere of radius 2 cm and the outer one of 4 cm. If the inner sphere is earthed and the outer one is charged with a charge of $2\ \mu\text{C}$ and isolated, calculate.
(a) The potential to which the outer sphere is raised.
(b) The charge retained on the outer surface of the outer sphere.

14. Calculate the charge on each capacitor and the potential difference across it in the circuits shown in figure for the cases :



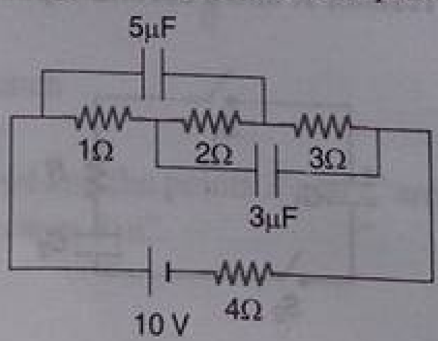
(a)



(b)

(i) switch S closed and
(ii) switch S open.
(iii) In figure (b) What is the potential of point A when S is open?

15. In the shown network, find the charges on capacitors of capacitances $5\ \mu\text{F}$ and $3\ \mu\text{F}$, in steady state.

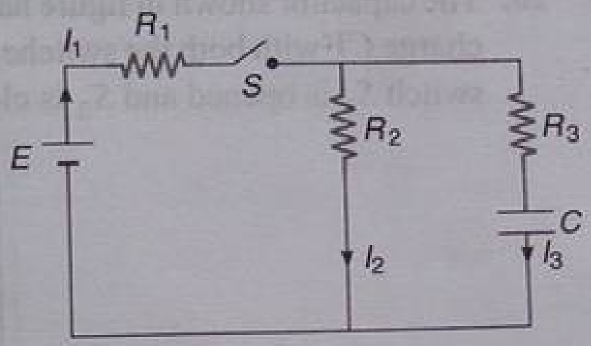


In the circuit shown, $E = 18\,\text{kV}$, $C = 10\,\mu\text{F}$, $R_1 = 4\,\text{M}\Omega$, $R_2 = 6\,\text{M}\Omega$, $R_3 = 3\,\text{M}\Omega$. With C completely uncharged, switch S is suddenly closed (at $t = 0$).

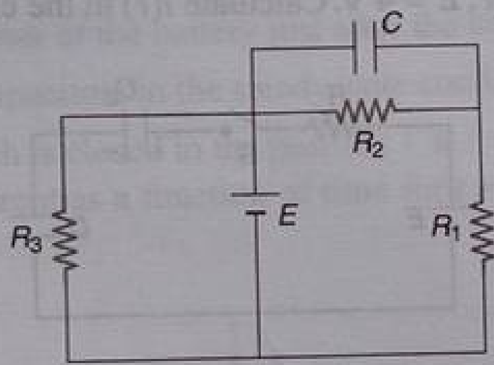
(a) Determine the current through each resistor for $t = 0$ and $t = \infty$.

(b) What are the values of V_2 (potential difference across R_2) at $t = 0$ and $t = \infty$?

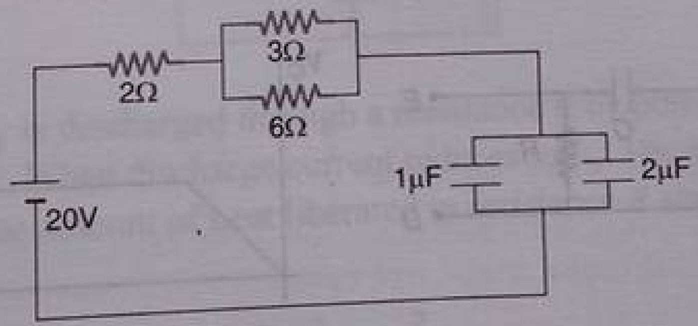
(c) Plot a graph of the potential difference V_2 *versus* t and determine the instantaneous value of V_2.



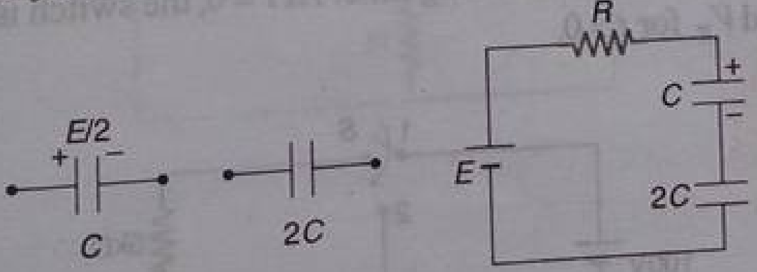
The charge on the capacitor is initially zero. Find the charge on the capacitor as a function of time t. All resistors are of equal value R.



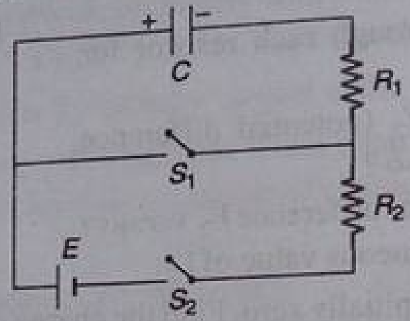
The capacitors are initially uncharged. In a certain time the capacitor of capacitance $2\,\mu\text{F}$ gets a charge of $20\,\mu\text{C}$. In that time interval find the heat produced by each resistor individually.



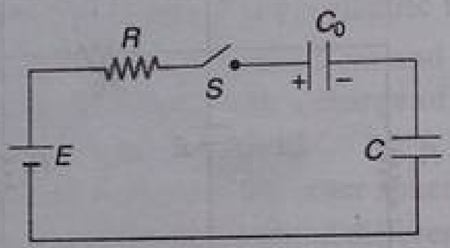
A capacitor of capacitance C has potential difference $E/2$ and another capacitor of capacitance $2C$ is uncharged. They are joined to form a closed circuit as shown in the figure:



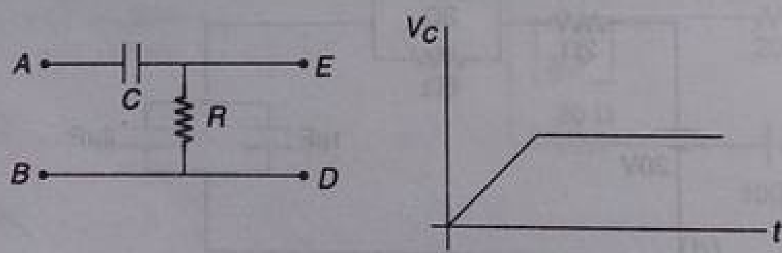
20. The capacitor shown in figure has been charged to a potential difference of V volt, so that it carries a charge CV with both the switches S_1 and S_2 remaining open. Switch S_1 is closed at $t=0$. At $t=R_1C$ switch S_1 is opened and S_2 is closed. Find the charge on the capacitor at $t=2R_1C+R_2C$.



21. The switch S is closed at $t=0$. The capacitor C is uncharged but C_0 has a charge $Q_0=2\,\mu\text{C}$ at $t=0$. If $R=100\,\Omega, C=2\,\mu\text{F}, C_0=2\,\mu\text{F}, E=4\,\text{V}$. Calculate $i(t)$ in the circuit.

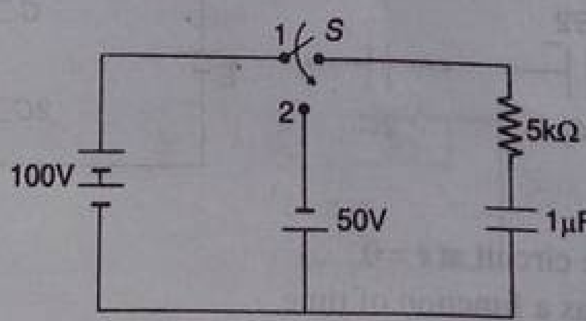


22. A time varying voltage is applied to the clamps A and B such that voltage across the capacitor plates is as shown in the figure. Plot the time dependence of voltage across the terminals of the resistance E and D.

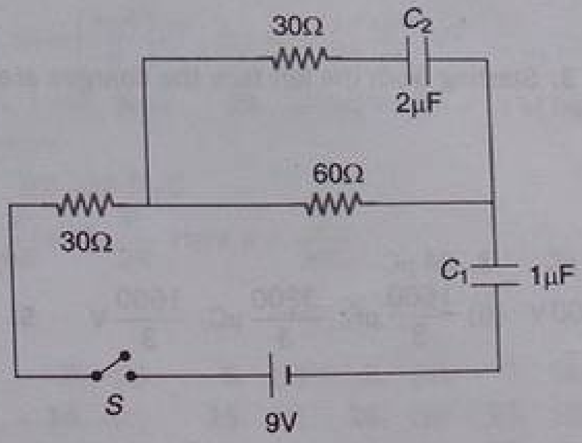


23. In the above problem if given graph is between V_{AB} and time. Then plot graph between V_{ED} and time.

24. Initially the switch is in position 1 for a long time. At $t=0$, the switch is moved from 1 to 2. Obtain expressions for V_C and V_R for $t>0$.



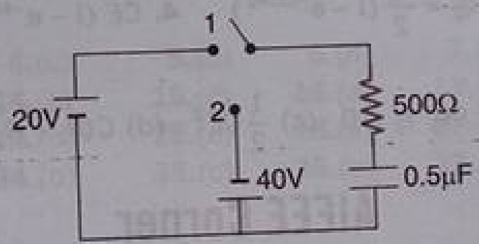
25. For the arrangement shown in the figure, the switch is closed at $t=0$. C_2 is initially uncharged while C_1 has a charge of $2\,\mu C$.



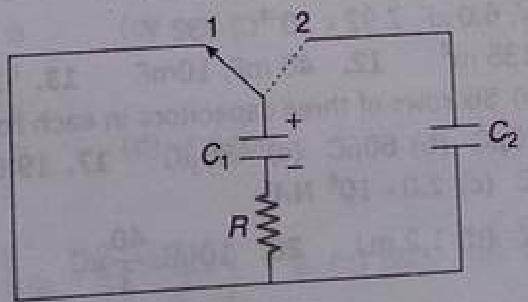
(a) Find the current coming out of the battery just after the switch is closed.

(b) Find the charge on the capacitors in the steady state condition.

26. In the given circuit, the switch is closed in the position 1 at $t=0$ and then moved to 2 after $250\,\mu s$. Derive an expression for current as a function of time for $t>0$. Also plot the variation of current with time.



27. A charged capacitor C_1 is discharged through a resistance R by putting switch S in position 1 of circuit shown in figure. When discharge current reduces to I_0. The switch is suddenly shifted to position 2. Calculate the amount of heat liberated in resistance R starting from this instant.



ANSWERS

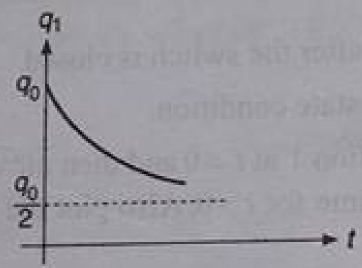
Introductory Exercise 22.1

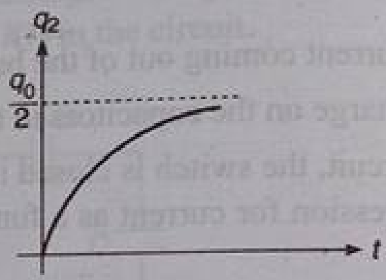
1. $[M^{-1}L^{-2}T^4A^2]$ 2. False 3. Starting from the left face the charges are, 3 μC, 7 μC, –7 μC, 3 μC
4. $\frac{\varepsilon_0 A}{d}, \frac{5dq}{2A\varepsilon_0}$

Introductory Exercise 22.2

1. 10 μC, 20 μC, 30 μC 2. 40 μC 3. 24 μC
4. (a) 800 μC, 800 V, 800 μC, 400 V (b) $\frac{1600}{3}$ μC, $\frac{3200}{3}$ μC, $\frac{1600}{3}$ V 5. 400μF

Introductory Exercise 22.3





2. 0.69 3. $q_1 = \frac{q_0}{2} + \frac{q_0}{2} e^{-2t/RC}$, $q_2 = \frac{q_0}{2}(1 - e^{-2t/RC})$ 4. $CE\,(1 - e^{-t/CR}) + q_0\ e^{-t/CR}$
5. (a) E/R_1 (b) $E/(R_1 + R_3)$
6. (a) $i_1 = E/R_1$, $i_2 = E/R_2$ (b) $i_1 = E/R_1$, $i_2 = 0$ (c) $\frac{1}{2}CE^2$ (d) $C(R_1 + R_2)$

AIEEE Corner

Subjective Questions (Level 1)

1. 1.1×10^8 m^2 3. $\frac{K\varepsilon_0 A}{2d}$ where $K = \frac{K_1}{2} + \frac{K_2 K_3}{K_2 + K_3}$ 5. (a) $\frac{5C}{3}$ (b) $\frac{4C}{3}$ (c) 2C
6. ±182 μC 7. (a) 604 V (b) 90.8 cm^2 (c) 16.3 μC/m^2 8. (a) 1.28 (b) 6.2×10^{-7} C/m^2
9. (a) 4.0 μF, 2.64×10^{-3}C, 660 V, 6.0 μF, 3.96×10^{-3} C, 660 V
(b) 4.0 μF, 5.28×10^{-4}C, 132 V, 6.0 μF, 7.92×10^{-4}C, 132 V
10. 2.83×10^{-2} J/m^3 11. 0.0135 m^2 12. 40 mF, 10mF 13. 10 V, 5 V
14. (a) Five capacitors in series (b) Six rows of three capacitors in each row.
15. 0.16 μF, 0.24 μF 16. (a) 120μC (b) 60μC (c) 480μC 17. 19.6 J
18. (a) 3.54×10^{-9} F (b) ±35.4 μC (c) 2.0×10^6 N/C
19. (a) 76 μC (b) 1.4 mJ (c) 11 V (d) 1.2 mJ 20. 10μC, $\frac{40}{3}$μC
21. (a) 2.5μF
(b) $Q_1 = 5.5 \times 10^{-4}$ C, $V_1 = 66$ V $Q_2 = 3.7 \times 10^{-4}$C, $V_2 = 88$ V
$Q_3 = Q_4 = 1.8 \times 10^{-4}$ C, $V_3 = V_4 = 44$ V, $Q_5 = Q_1, V_5 = V_1$
22. 78.68 V, 151.32 V 23. 60μC 24. (a) 3μF (b) 60μC (c) 30μC (d) 20μC (e) 20μC
25. (a) $q_1 = q_3 = 9$ μC, $q_2 = q_4 = 16$ μC (b) $q_1 = 8.4$ μC, $q_2 = 16.8$ μC, $q_3 = 10.8$ μC, $q_4 = 14.4$ μC

26. $q_2 = q_3 = \dfrac{C_1V_0}{1+\dfrac{C_1}{C_2}+\dfrac{C_1}{C_3}}$, $q_1 = C_1V_0 - \dfrac{C_1V_0}{1+\dfrac{C_1}{C_2}+\dfrac{C_1}{C_3}}$

27. (a) 2 V (b) $U_i = \dfrac{1}{2}\left(\dfrac{\varepsilon_0 A}{d}\right)V^2, U_f = \left(\dfrac{\varepsilon_0 A}{d}\right)V^2$ (c) $W = \dfrac{1}{2}\left(\dfrac{\varepsilon_0 A}{d}\right)V^2$

28. (a) 1 mA, 1 mA, 0 (b) 2 mA, 1 mA, 3mA (d) –36 μC on both the capacitors

29. (a) 18 V (b) *a* is at higher potential (c) 6 V

30. (a) –6.0 V (b) *b* (c) 6.0 V (d) –54.0 μC

31. (a) $\dfrac{CV}{2}(1-e^{-\alpha t})$ (b) $\dfrac{V}{2R} - \dfrac{V}{6R}e^{-\alpha t}, \dfrac{V}{2R}$ Here $\alpha = \dfrac{2}{3RC}$

Objective Questions (Level 1)

1. (c)	**2.** (d)	**3.** (c)	**4.** (c)	**5.** (c)	**6.** (d)	**7.** (c)	**8.** (b)	**9.** (b)	**10.** (c)
11. (a)	**12.** (b)	**13.** (b)	**14.** (c)	**15.** (c)	**16.** (a)	**17.** (d)	**18.** (b)	**19.** (b)	**20.** (b)
21. (a)	**22.** (c)	**23.** (d)	**24.** (c)	**25.** (d)	**26.** (b)	**27.** (b)			

JEE Corner

Assertion and Reason

1. (d)	**2.** (a)	**3.** (a,b)	**4.** (a,b)	**5.** (d)	**6.** (d)	**7.** (b)	**8.** (d)	**9.** (b)	**10.** (b)

Objective Questions (Level 2)

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

More than One Correct Options

1.(a,c,d)	**2.**(b,c,d)	**3.**(b,c)	**4.**(a,b,d)	**5.**(b,c)	**6.**(a,d)	**7.**(a,b,d)	**8.**(a,b,c)	**9.**(a,b,c,d)	**10.**(b,c)

Match the Columns

1. (a) → q (b) → p (c) → p (d) → p
2. (a) → s (b) → p (c) → r (d) → s
3. (a) → q (b) → p,r (c) → q (d) → p,s
4. (a) → r (b) → p (c) → s
5. (a) → s (b) → s (c) → s
6. (a) → p (b) → p,q (c) → s (d) → p,q,r

Subjective Questions (Level 2)

1. (a) $\dfrac{5}{3}\left(\dfrac{\varepsilon_0 A}{d}\right)$ (b) $q_3 = \dfrac{4}{3}\left(\dfrac{\varepsilon_0 A V_0}{d}\right), q_5 = \dfrac{2}{3}\left(\dfrac{\varepsilon_0 A V_0}{d}\right)$

2. (a) 80 V (b) 57.6 mJ, 38.4 mJ

3. $-\dfrac{19}{5}V, -\dfrac{2}{5}V, \dfrac{7}{5}V, \dfrac{14}{5}V$

4. 2.5 A, 0.6 A

5. 44.4 mJ

6. (a) 3A, 2.67A (b) 24 V (c) 11.1 μs

7. $V_N - V_M = \dfrac{110}{3}$ volt

8. $q_1 = EC_2, q_2 = \dfrac{-EC_1C_2}{(C_1+C_2)}$

9. (i) 90μC, 210μC, 150μC (ii) (a) 47.4 mJ (b) 18 mJ

10. (a) $q_1 = \left(\frac{C_1}{C_1 + C_2}\right) q_0$ and $q_2 = \left(\frac{C_2}{C_1 + C_2}\right) q_0$, $i = \frac{q_0}{RC_1} e^{-t/RC}$

(b) $\Delta H = \frac{q_0^2 C_2}{2C_1(C_1 + C_2)}$ Here $C = \frac{C_1 C_2}{C_1 + C_2}$

11. $0.193\,\mu A$ 12. (a) $\frac{Q^2 x}{2\varepsilon_0 A}$ (b) $\left(\frac{Q^2}{2\varepsilon_0 A}\right) \cdot dx$ (c) $\frac{Q^2}{2\varepsilon_0 A}$ 13. (a) 2.25×10^5 V (b) $+1\,\mu C$

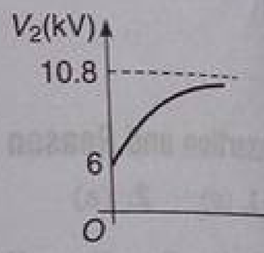
14.

		Fig. (a)			Fig. (b)	
		$6\,\mu F$	$3\,\mu F$	$1\,\mu F$	$6\,\mu F$	$2\,\mu F$
(i)	P.D (volts)	30	30	0	10	30
	charge (μC)	180	90	0	60	60
(ii)	P.D (volts)	0	90	100	25	75
	charge (μC)	0	270	100	150	150
(iii)	$V_A = 75$ volt					

15. $15\,\mu C$, $15\,\mu C$

16. (a) At $t = 0$, $i_1 = 3$ mA, $i_2 = 1$ mA, $i_3 = 2$ mA At $t = \infty$, $i_1 = i_2 = 1.8$ mA, $i_3 = 0$ (b) At $t = 0$, $V_2 = 6$ kV At $t = \infty$, $V_2 = 10.8$ kV

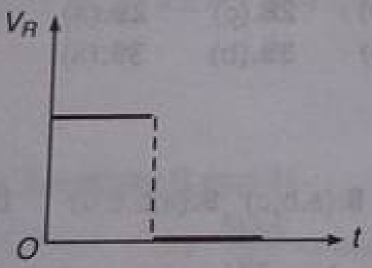
(c) $V_2 = (10.8 - 4.8\,e^{-t/54})$ kV



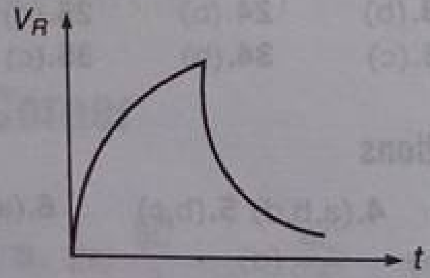
17. $q = \frac{CE}{2}\left(1 - e^{-\frac{2t}{CR}}\right)$ 18. $H_2 = 0.075$ mJ, $H_3 = 0.05$ mJ, $H_6 = 0.025$ mJ

19. (a) $\frac{E}{2R}$ (b) $\frac{CE}{6}[5 - 2e^{-3t/2RC}]$ 20. $EC\left(1 - \frac{1}{e}\right) + \frac{VC}{e^2}$ 21. $(0.03\,e^{-10^4 t})$ A

22.



23.



24. $V_C = 50\,(3\,e^{-200t} - 1)$, $V_R = 150\,e^{-200t}$ 25. (a) $\frac{7}{50}$ A or $\frac{11}{50}$ A (b) $Q_1 = 9\,\mu C$, $Q_2 = 0$

26. $i = (0.04 e^{-4000t})$ A for $t \le 250\,\mu s$, $= -(0.11\,e^{-4000t})$ A for $t \ge 250\,\mu s$

For i - t graph, see the hints.

27. $\frac{(I_0 R)^2 C_1 C_2}{2(C_1 + C_2)}$

23

Magnetics

hapter Contents

Solved Examples

Level 1

Example 1 *A magnetic field of* $(4.0 \times 10^{-3}\,\hat{\mathbf{k}})$ *T exerts a force* $(4.0\,\hat{\mathbf{i}} + 3.0\,\hat{\mathbf{j}}) \times 10^{-10}$ *N on a particle having a charge* 10^{-9} *C and moving in the x-y plane. Find the velocity of the particle.*

Solution Given, $\vec{\mathbf{B}} = (4 \times 10^{-3}\,\hat{\mathbf{k}})\,\text{T},\ q = 10^{-9}\,\text{C}$

and Magnetic force $\vec{\mathbf{F}}_m = (4.0\,\hat{\mathbf{i}} + 3.0\,\hat{\mathbf{j}}) \times 10^{-10}\,\text{N}$

Let velocity of the particle in x-y plane be,

$$\vec{\mathbf{v}} = v_x\,\hat{\mathbf{i}} + v_y\,\hat{\mathbf{j}}$$

Then from the relation,

$$\vec{\mathbf{F}}_m = q\,(\vec{\mathbf{v}} \times \vec{\mathbf{B}})$$

We have

$$(4.0\,\hat{\mathbf{i}} + 3.0\,\hat{\mathbf{j}}) \times 10^{-10} = 10^{-9}\,[(v_x\,\hat{\mathbf{i}} + v_y\,\hat{\mathbf{j}}) \times (4 \times 10^{-3}\,\hat{\mathbf{k}})]$$

$$= (4v_y \times 10^{-12}\,\hat{\mathbf{i}} - 4v_x \times 10^{-12}\,\hat{\mathbf{j}})$$

Comparing the coefficients of $\hat{\mathbf{i}}$ and $\hat{\mathbf{j}}$ we have,

$$4 \times 10^{-10} = 4v_y \times 10^{-12}$$

$\therefore$ $$v_y = 10^2\ \text{m/s} = 100\ \text{m/s}$$

and $$3.0 \times 10^{-10} = -4v_x \times 10^{-12}$$

$\therefore$ $$v_x = -75\ \text{m/s}$$

$\therefore$ $$\vec{\mathbf{v}} = -75\hat{\mathbf{i}} + 100\hat{\mathbf{j}}$$ **Ans.**

Example 2 *A square of side 2.0 m is placed in a uniform magnetic field* $\vec{\mathbf{B}} = 2.0$ *T in a direction perpendicular to the plane of the square inwards. Equal current* $i = 3.0$ *A is flowing in the directions shown in figure. Find the magnitude of magnetic force on the loop.*

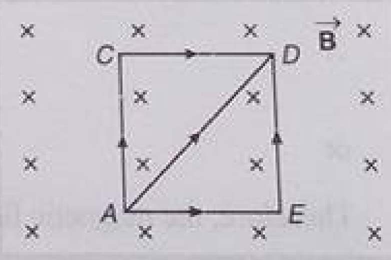


Fig. 23.90

Solution Force on wire ACD = Force on AD = Force on AED

$\therefore$ Net force on the loop $= 3\,(\vec{\mathbf{F}}_{AD})$

or $$F_{\text{net}} = 3\,(i)\,(AD)\,(B)$$

$$= (3)(3.0)(2\sqrt{2})(2.0)\text{ N}$$
$$= 36\sqrt{2}\text{ N}$$

Direction of this force is towards *EC*.

Example 3 *A charged particle carrying charge $q = 1\,\mu C$ moves in uniform magnetic field with velocity $v_1 = 10^6$ m/s at angle 45° with x-axis in the x-y plane and experiences a force $F_1 = 5\sqrt{2}$ mN along the negative z-axis. When the same particle moves with velocity $v_2 = 10^6$ m/s along the z-axis it experiences a force F_2 in y-direction. Find*

(a) magnitude and direction of the magnetic field,

(b) the magnitude of the force F_2.

Solution F_2 is in y-direction when velocity is along z-axis. Therefore, magnetic field should be along x-axis. So let,

$$\vec{B} = B_0\hat{i}$$

(a) Given
$$\vec{v}_1 = \frac{10^6}{\sqrt{2}}\hat{i} + \frac{10^6}{\sqrt{2}}\hat{j}$$

and
$$\vec{F}_1 = -5\sqrt{2}\times 10^3\,\hat{k}$$

From the equation,

$$\vec{F} = q(\vec{v}\times\vec{B})$$

we have
$$(-5\sqrt{2}\times 10^{-3})\,\hat{k} = (10^{-6})\left[\left(\frac{10^6}{\sqrt{2}}\hat{i} + \frac{10^6}{\sqrt{2}}\hat{j}\right)\times(B_0\hat{i})\right]$$
$$= -\frac{B_0}{\sqrt{2}}\hat{k}$$

$\therefore$
$$\frac{B_0}{\sqrt{2}} = 5\sqrt{2}\times 10^{-3}$$

or
$$B_0 = 10^{-2}\text{ T}$$

Therefore, the magnetic field is,

$$\vec{B} = (10^{-2}\,\hat{i})\text{ T}$$ **Ans.**

(b)
$$F_2 = B_0 q v_2 \sin 90°$$

As the angle between $\vec{B}$ and $\vec{v}$ in this case is 90°.

$\therefore$
$$F_2 = (10^{-2})(10^{-6})(10^6) = 10^{-2}\text{ N}$$ **Ans.**

Example 4 *Figure shows a current loop having two circular arcs joined by two radial lines. Find the magnetic field B at the centre O.*

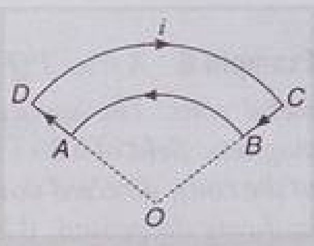


Fig. 23.91

Solution Magnetic field at point O, due to wires CB and AD will be zero.

Magnetic field due to wire BA will be,

$$B_1 = \left(\frac{\theta}{2\pi}\right)\left(\frac{\mu_0 i}{2a}\right)$$

Direction of field $\vec{\mathbf{B}}_1$ is coming out of the plane of the figure.

Similarly, field at O due to arc DC will be,

$$B_2 = \left(\frac{\theta}{2\pi}\right)\left(\frac{\mu_0 i}{2b}\right)$$

Direction of field $\vec{\mathbf{B}}_2$ is going into the plane of the figure. The resultant field at O is,

$$B = B_1 - B_2 = \frac{\mu_0 i\theta (b-a)}{4\pi ab}$$ **Ans.**

Coming out of the plane.

Example 5 *The magnetic field B due to a current carrying circular loop of radius* 12 *cm at its centre is* 0.5×10^{-4} *T. Find the magnetic field due to this loop at a point on the axis at a distance of* 5.0 *cm from the centre.*

Solution Magnetic field at the centre of a circular loop is,

$$B_1 = \frac{\mu_0 i}{2R}$$

and that at an axial point,

$$B_2 = \frac{\mu_0 iR^2}{2(R^2+x^2)^{3/2}}$$

Thus,

$$\frac{B_2}{B_1} = \frac{R^3}{(R^2+x^2)^{3/2}}$$

or

$$B_2 = B_1\left[\frac{R^3}{(R^2+x^2)^{3/2}}\right]$$

Substituting the values, we have

$$B_2 = (0.5\times 10^{-4})\left[\frac{(12)^3}{(144+25)^{3/2}}\right]$$

$$= 3.9 \times 10^{-5}\ \text{T}$$ **Ans.**

Example 6 *A wire PQ of mass 10 g is at rest on two parallel metal rails. The separation between the rails is 4.9 cm. A magnetic field of 0.80 T is applied perpendicular to the plane of the rails, directed downwards. The resistance of the circuit is slowly decreased. When the resistance decreases to below 20 Ω, the wire PQ begins to slide on the rails. Calculate the coefficient of friction between the wire and the rails.*

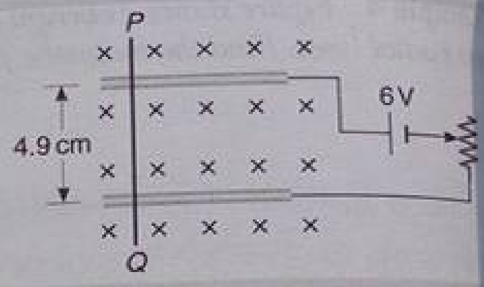


Fig. 23.92

Solution Wire PQ begins to slide when magnetic force is just equal to the force of friction, *i.e.*,

$$\mu mg = ilB\sin\theta \qquad (\theta = 90°)$$

Here,
$$i = \frac{E}{R} = \frac{6}{20} = 0.3\ \text{A}$$

∴
$$\mu = \frac{ilB}{mg}$$
$$= \frac{(0.3)(4.9\times10^{-2})(0.8)}{(10\times10^{-3})(9.8)}$$
$$= 0.12$$
Ans.

Example 7 *What is the smallest value of B that can be set up at the equator to permit a proton of speed 10^7 m/s to circulate around the earth?*
$[R = 6.4\times10^6\ m, m_p = 1.67\times10^{-27}\ kg]$.

Solution From the relation

$$r = \frac{mv}{Bq}$$

We have,
$$B = \frac{mv}{qr}$$

Substituting the values, we have

$$B = \frac{(1.67\times10^{-27})(10^7)}{(1.6\times10^{-19})(6.4\times10^6)}$$
$$= 1.6\times10^{-8}\ \text{T}$$
Ans.

Example 8 *Deuterons in a cyclotron describes a circle of radius 32.0 cm. Just before emerging from the D's. The frequency of the applied alternating voltage is 10 MHz. Find,*

(a) the magnetic flux density (i.e., the magnetic field).

(b) the energy and speed of the deuterons upon emergence.

Solution (a) Frequency of the applied emf = Cyclotron frequency

or
$$f = \frac{Bq}{2\pi m}$$

$$\therefore \quad B = \frac{2\pi mf}{q}$$

$$= \frac{(2)(3.14)(2\times1.67\times10^{-27})(10\times10^{6})}{1.6\times10^{-19}}$$

$$= 1.30\ \text{T}$$ **Ans.**

(b) The speed of deuterons on the emergence from the cyclotron,

$$v = \frac{BqR}{m} = 2\pi fR$$

$$= (2)(3.14)(10\times10^{6})(32\times10^{-2})$$

$$= 2.01\times10^{7}\ \text{m/s}$$

$$\therefore \quad \text{Energy of deuterons} = \frac{1}{2}mv^2$$

$$= \frac{1}{2}\times(2\times1.67\times10^{-27})(2.01\times10^{7})^2\ \text{J}$$

$$= 4.22\ \text{MeV}$$ **Ans.**

Note $1\ MeV = 1.6\times10^{-13}\ J$

Example 9 *A wire shaped to a regular hexagon of side 2 cm carries a current of 2 A. Find the magnetic field at the centre of the hexagon.*

Solution

$$\theta = 30°$$

$$\frac{BC}{OC} = \tan\theta \qquad (BC = 1\ \text{cm})$$

$$\frac{1}{r} = \tan 30° \frac{1}{\sqrt{3}}$$

$$\therefore \quad r = \sqrt{3}\ \text{cm}$$

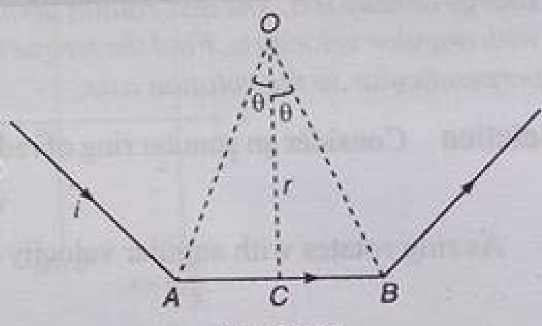


Fig. 23.93

Net magnetic field at O = 6 times the magnetic field due to one side.

$$\therefore \quad B = 6\left[\frac{\mu_0}{2\pi}\frac{i}{r}(\sin\theta + \sin\theta)\right]$$

$$= \frac{6(2\times10^{-7})(2)}{\sqrt{3}\times10^{-2}}\left(\frac{1}{2}+\frac{1}{2}\right)$$

$$= 1.38\times10^{-4}\ \text{T}$$ **Ans.**

Example 10 *In the Bohr model of the hydrogen atom the electron circulates around the nucleus in a path of radius* 5×10^{-11} *m at a frequency of* 6.8×10^{15} *Hz.*

(a) What value of magnetic field is set up at the centre of the orbit?

(b) What is the equivalent magnetic dipole moment?

Solution (a) An electron moving around the nucleus is equivalent to a current,

$$i = qf$$

Magnetic field at the centre,

$$B = \frac{\mu_0 i}{2R} = \frac{\mu_0 qf}{2R}$$

Substituting the values, we have

$$B = \frac{(4\pi \times 10^{-7})(1.6 \times 10^{-19})(6.8 \times 10^{15})}{2 \times 5.1 \times 10^{-11}}$$

$$= 13.4 \text{ T}$$ **Ans.**

(b) The current carrying circular loop is equivalent to a magnetic dipole, with magnetic dipole moment,

$$M = NiA = (Nqf\,\pi R^2)$$

Substituting the values, we have

$$M = (1)(1.6 \times 10^{-19})(6.8 \times 10^{15})(3.14)(5.1 \times 10^{-11})^2$$

$$= 8.9 \times 10^{-24} \text{ A-m}^2$$ **Ans.**

Level 2

Example 1 *A flat dielectric disc of radius R carries an excess charge on its surface. The surface charge density is σ. The disc rotates about an axis perpendicular to its plane passing through the centre with angular velocity ω. Find the torque on the disc if it is placed in a uniform magnetic field B directed perpendicular to the rotation axis.*

Solution Consider an annular ring of radius r and of thickness dr on this disc. Charge within this ring,

$$dq = (\sigma)(2\pi r dr)$$

As ring rotates with angular velocity ω, the equivalent current is,

$$i = (dq)(\text{frequency})$$

$$= (\sigma)(2\pi r dr)\left(\frac{\omega}{2\pi}\right)$$

or

$$i = \sigma\omega r dr$$

Magnetic moment of this annular ring,

$$M = iA = (\sigma\omega r dr)(\pi r^2)$$

(along the axis of rotation)

Torque on this ring,

$$d\tau = MB \sin 90° = (\sigma\omega\pi r^3 B)\, dr$$

∴ Total torque on the disc is,

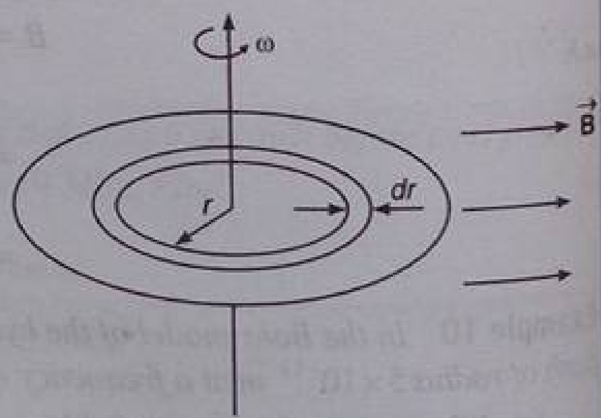


Fig. 23.94

$$\tau = \int_0^R d\tau = (\sigma\omega\pi B)\int_0^R r^3\,dr$$

$$= \frac{\sigma\omega\pi BR^4}{4}$$ **Ans.**

Example 2 *Three infinitely long thin wires, each carrying current i in the same direction, are in the X-Y plane of a gravity free space. The central wire is along the y-axis while the other two are along* $x = \pm d$.

(i) Find the locus of the points for which the magnetic field B is zero.

(ii) If the central wire is displaced along the z-direction by a small amount and released, show that it will execute simple harmonic motion. If the linear density of the wires is λ, find the frequency of oscillation.

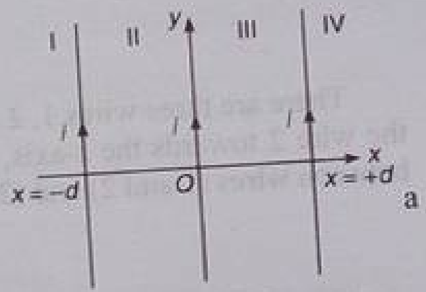


Fig. 23.95

Solution (i) Magnetic field will be zero on the y-axis, *i.e.*, $x = 0 = z$.

Magnetic field can not be zero in region I and region IV because in region I magnetic field will be along positive z direction due to all the three wires, while in region IV magnetic field will be long negative z-axis and due to all the three wires. It can be zero only in region II and III.

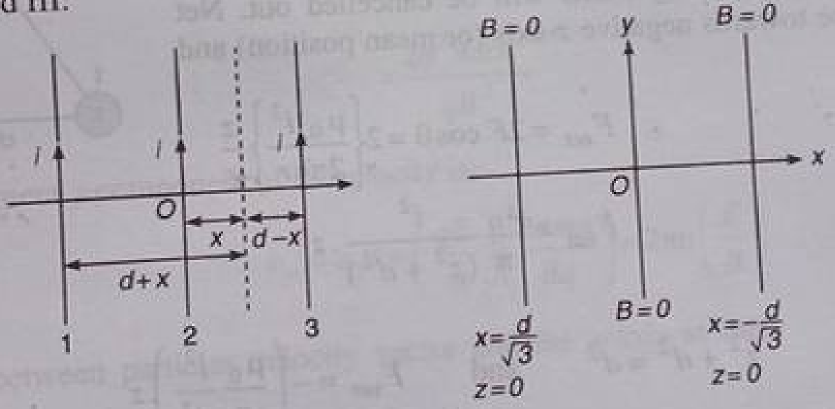


Fig. 23.96

Let magnetic field is zero on line $z = 0$ and $x = x$ (shown as dotted). The magnetic field on this line due to wires 1 and 2 will be along negative z-axis and due to wire 3 along positive z-axis. Thus,

$$B_1 + B_2 = B_3$$

or $$\frac{\mu_0}{2\pi}\frac{i}{(d+x)} + \frac{\mu_0 i}{2\pi x} = \frac{\mu_0}{2\pi}\frac{i}{(d-x)}$$

or $$\frac{1}{d+x} + \frac{1}{x} = \frac{1}{d-x}$$

This equation gives $$x = \pm\frac{d}{\sqrt{3}}$$

Hence, there will be two lines

$$x = \frac{d}{\sqrt{3}} \quad \text{and} \quad x = -\frac{d}{\sqrt{3}} \qquad (z = 0)$$

where magnetic field is zero. **Ans.**

(ii) In this part we change our co-ordinate axes system, just for better understanding.

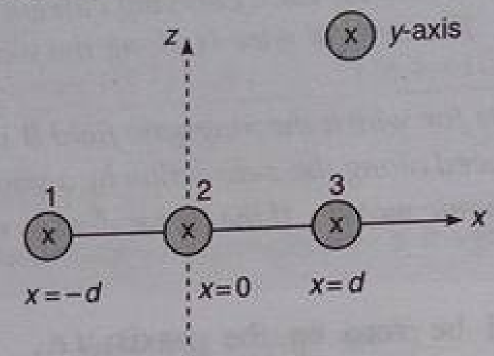


Fig. 23.97

There are three wires 1, 2 and 3 as shown in figure. If we displace the wire 2 towards the z-axis, then force of attraction per unit length between wires (1 and 2) and (2 and 3) will be given by

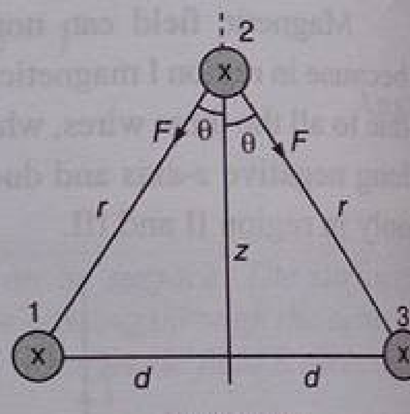


Fig. 23.98

$$F = \frac{\mu_0}{2\pi}\frac{i^2}{r}$$

The components of F along x-axis will be cancelled out. Net resultant force will be towards negative z-axis (or mean position) and will be given by

$$F_{net} = 2F\cos\theta = 2\left\{\frac{\mu_0}{2\pi}\frac{i^2}{r}\right\}\frac{z}{r}$$

$$F_{net} = \frac{\mu_0}{\pi}\frac{i^2}{(z^2+d^2)}.z$$

If $z << d$, then

$$z^2 + d^2 \approx d^2 \quad \text{and} \quad F_{net} = -\left(\frac{\mu_0}{\pi}\frac{i^2}{d^2}\right)z$$

Negative sign implies that F_{net} is restoring in nature.

Therefore, $\quad F_{net} \propto -z$

i.e., the wire will oscillate simple harmonically.

Let a be the acceleration of wire in this position and λ the mass per unit length of wire then

$$F_{net} = \lambda a = -\left(\frac{\mu_0}{\pi}\frac{i^2}{d^2}\right)z \quad \text{or} \quad a = -\left(\frac{\mu_0 i^2}{\pi\lambda d^2}\right)z$$

$\therefore$ Frequency of oscillation

$$f = \frac{1}{2\pi}\sqrt{\left|\frac{\text{acceleration}}{\text{displacement}}\right|}$$

$$= \frac{1}{2\pi}\sqrt{\left|\frac{a}{z}\right|} = \frac{1}{2\pi}\frac{i}{d}\sqrt{\frac{\mu_0}{\pi\lambda}} \quad \text{or} \quad f = \frac{i}{2\pi d}\sqrt{\frac{\mu_0}{\pi\lambda}}$$

A

Example 3 *Uniform electric and magnetic fields with strength E and B are directed along the y-axis. A particle with specific charge q/m leaves the origin in the direction of x-axis with an initial velocity v_0. Find*

(a) the y-coordinate of the particle when it crosses the y-axis for nth time.

(b) the angle α between the particle's velocity vector and the y-axis at that moment.

Solution (a) As discussed in Art 13.4 path of the particle is a helix of increasing pitch. The axis of the helix is parallel to y-axis (parallel to $\vec{\mathbf{E}}$) and plane of circle of the helix is xz (perpendicular to $\vec{\mathbf{B}}$). The particle will cross the y-axis after time,

$$t = nT = n\left(\frac{2\pi m}{Bq}\right) = \frac{2\pi mn}{Bq}$$

The y-coordinate of particle at this instant is,

$$y = \frac{1}{2}a_y t^2$$

where,

$$a_y = \frac{F_y}{m} = \frac{qE}{m}$$

$$y = \frac{1}{2}\left(\frac{qE}{m}\right)\left(\frac{2\pi mn}{Bq}\right)^2$$

$$= \frac{2n^2 mE\pi^2}{qB^2}$$ **Ans.**

(b) At this moment y component of its velocity is,

$$v_y = a_y t = \left(\frac{qE}{m}\right)\left(\frac{2\pi mn}{Bq}\right) = 2\pi n\left(\frac{E}{B}\right)$$

The angle α between particles velocity vector and the y-axis at this moment is,

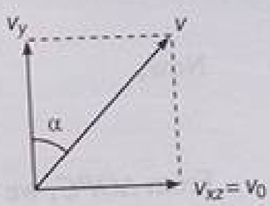


Fig. 23.99

$$\alpha = \tan^{-1}\left(\frac{v_{xz}}{v_y}\right)$$

Here,

$$v_{xz} = \sqrt{v_x^2 + v_z^2} = v_0$$

or

$$\alpha = \tan^{-1}\left(\frac{Bv_0}{2\pi nE}\right)$$ **Ans.**

Example 4 *For the cylinder with the hole in example 7, show that the magnetic field inside the hole is uniform and find its magnitude and direction.*

Solution Let us find the magnetic field at point P inside the cavity at a distance r_1 from O and r_2 from C.

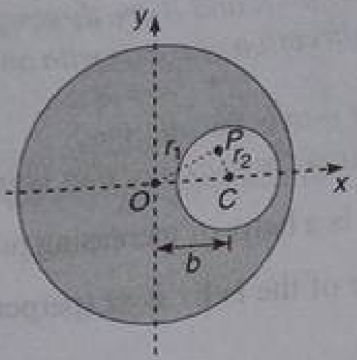


Fig. 23.100

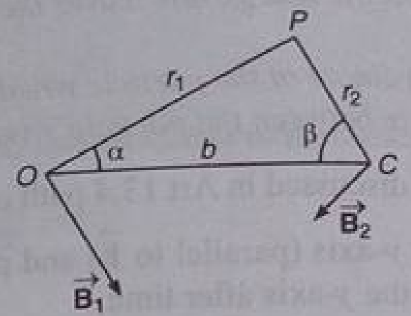


Fig. 23.101

At point P magnetic field due to i_1 is B_1 (perpendicular to OP) and is $\vec{\mathbf{B}}_2$ due to i_2 (perpendicular to CP) in the directions shown. Although $\vec{\mathbf{B}}_1$ and $\vec{\mathbf{B}}_2$ are actually at P, but for better understanding they are drawn at O and C respectively. Let B_x be the x component of resultant of $\vec{\mathbf{B}}_1$ and $\vec{\mathbf{B}}_2$ and B_y its y component. Then,

$$B_x = B_1 \sin\alpha - B_2 \sin\beta$$

$$= \left(\frac{\mu_0}{2\pi}\frac{i_1}{R^2} r_1\right)\sin\alpha - \left(\frac{\mu_0}{2\pi}\frac{i_2}{a^2}\cdot r_2\right)\sin\beta$$

$$= \left(\frac{\mu_0}{2\pi}\frac{J\pi R^2}{R^2}\cdot r_1 \sin\alpha\right) - \left(\frac{\mu_0}{2\pi}\frac{J.\pi a^2}{a^2} r_2 \sin\beta\right)$$

$$= \frac{\mu_0 J}{2}(r_1 \sin\alpha - r_2 \sin\beta)$$

$$= 0$$

Because in ΔOPC,

$$\frac{r_1}{\sin\beta} = \frac{r_2}{\sin\alpha} \qquad \text{or} \qquad r_1 \sin\alpha - r_2 \sin\beta = 0.$$

Now,

$$B_y = -(B_1 \cos\alpha + B_2 \cos\beta)$$

$$= -\frac{\mu_0 J}{2}(r_1 \cos\alpha + r_2 \cos\beta)$$

From ΔOPC, we can see that

$$r_1 \cos\alpha + r_2 \cos\beta = b$$

or

$$B_y = -\frac{\mu_0 J b}{2} = -\frac{\mu_0 i b}{2\pi(R^2 - a^2)} = \text{constant}.$$

Thus, we can see that net magnetic field at point P is along negative y-direction and constant in magnitude. **Proved**

Note *(i) That $\angle OPC$ is not necessarily 90°. At some point it may be 90°.*

(ii) At point C magnetic field due to i_2 is zero (i.e., $B_2 = 0$) while that due to i_1 is $\frac{\mu_0}{2\pi}\frac{i_1}{R^2} b$ in negative y-direction. Substituting, $i_1 = J(\pi R^2)$ we get,

$$B = B_2 = \frac{\mu_0 ib}{2\pi(R^2 - a^2)}$$ *(along negative y-direction)*

This agress with the result derived above.

Example 5 *A particle of charge q and mass m is projected from the origin with velocity $\vec{v} = v_0\hat{i}$ in a nonuniform magnetic field $\vec{B} = -B_0x\hat{k}$. Here v_0 and B_0 are positive constants of proper dimensions. Find the maximum positive x-coordinate of the particle during its motion.*

Solution Magnetic field is along negative z-direction. So in the coordinate axes shown in figure, it is perpendicular to paper inwards. (⊗) Magnetic force on the particle at origin is along positive y-direction. So it will rotate in x-y plane as shown. The path is not a perfect circle as the magnetic field is nonuniform. Speed of the particle in magnetic field remains constant. Magnetic force is always perpendicular to velocity. Let at point P (x, y) its velocity vector makes an angle θ with positive x-axis. Then magnetic force $\vec{F}_m$ will be at angle θ with positive y-direction. So,

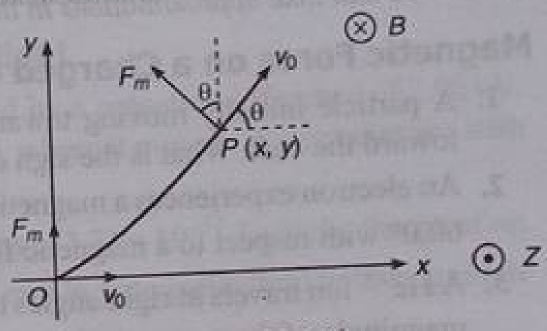


Fig. 23.102

$$a_y = \left(\frac{F_m}{m}\right)\cos\theta$$

$$\frac{dv_y}{dt} = \frac{(B_0x)(qv_0\cos\theta)}{m} \qquad [F_m = Bqv_0 \sin 90°]$$

$$\therefore \quad \left(\frac{dv_y}{dx}\right)\cdot\left(\frac{dx}{dt}\right) = \left(\frac{B_0qx}{m}\right)(v_0\cos\theta)$$

Here,

$$\frac{dx}{dt} = v_x = v_0\cos\theta$$

$$\therefore \quad \frac{dv_y}{dx} = \left(\frac{B_0q}{m}\right)x$$

$$\therefore \quad \int_0^{v_0} dv_y = \left(\frac{B_0q}{m}\right)\int_0^{x_{max}} x\,dx$$

$$\therefore \quad v_0 = \left(\frac{B_0q}{m}\right)\left(\frac{x_{max}^2}{2}\right)$$

$$\therefore \quad x_{max} = \sqrt{\frac{2mv_0}{B_0q}}$$ **Ans.**

Note *At maximum x-displacement velocity is along positive y-direction.*

EXERCISES

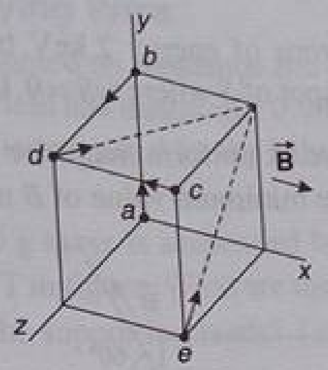
AIEEE Corner

Subjective Questions (Level 1)

Note *You can take approximations in the answers.*

Magnetic Force on a Charged Particle in Motion

1. A particle initially moving towards south in a vertically downward magnetic field is deflected toward the east. What is the sign of the charge on the particle?
2. An electron experiences a magnetic force of magnitude 4.60×10^{-15} N, when moving at an angle of $60.0°$ with respect to a magnetic field of magnitude 3.50×10^{-3} T. Find the speed of the electron.
3. A He^{2+} ion travels at right angles to a magnetic field of 0.80 T with a velocity of 10^5 m/s. Find the magnitude of the magnetic force on the ion.
4. An electron has velocity $\vec{v} = (2.0 \times 10^6 \text{ m/s})\hat{i} + (3.0 \times 10^6 \text{ m/s})\hat{j}$. Magnetic field present in the region is $\vec{B} = (0.030 \text{ T})\hat{i} - (0.15 \text{ T})\hat{j}$.
   (a) Find the force on electron.
   (b) Repeat your calculation for a proton having the same velocity.
5. An electon moves through a uniform magnetic field given by $\vec{B} = B_x\hat{i} + (3B_x)\hat{j}$. At a particular instant, the electron has the velocity $\vec{v} = (2.0\hat{i} + 4.0\hat{j})$ m/s and the magnetic force acting on it is $(6.4 \times 10^{-19} \text{ N})\hat{k}$. Find B_x.
6. A charged particle carrying charge $q = 1\,\mu\text{C}$ moves in uniform magnetic field with velocity $v_1 = 10^6$ m/s at angle 45° with x-axis in the x-y plane and experiences a force $F_1 = 5\sqrt{2}$ mN along the negative z-axis. When the same particle moves with velocity $v_2 = 10^6$ m/s along the z-axis it experiences a force F_2 in y-direction. Find
   (a) magnitude and direction of the magnetic field,
   (b) the magnitude of the force F_2.
7. A particle with charge $7.80\,\mu\text{C}$ is moving with velocity $\vec{v} = -(3.80 \times 10^3 \text{ m/s})\hat{j}$. The magnetic force on the particle is measured to be $\vec{F} = +(7.60 \times 10^{-3}\text{N})\hat{i} - (5.20 \times 10^{-3} \text{ N})\hat{k}$.
   (a) Calculate the components of the magnetic field you can find from this information.
   (b) Are there components of the magnetic field that are not determined by the measurement of the force? Explain.
   (c) Calculate the scalar product $\vec{B} \cdot \vec{F}$. What is the angle between $\vec{B}$ and $\vec{F}$?
8. Each of the lattered points at the corners of the cube in figure represents a positive charge q moving with a velocity of magnitude v in the direction inidicated. The region in the figure is in a uniform magnetic field $\vec{B}$, parallel to the x-axis and directed toward the right. Find the magnitude and direction of the force on each charge.



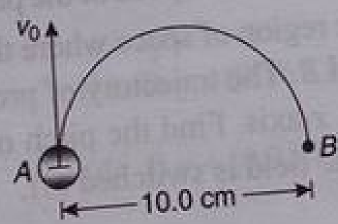
Motion of Charged Particle in Uniform Magnetic Field

9. An electron in the beam of a TV picture tube is accelerated by a potential difference of 2.00 kV. Then, it passes through region of transverse magnetic field, where it moves in a circular arc with radius 0.180 m. What is the magnitude of the field?

10. A deuteron (the nucleus of an isotope of hydrogen) has a mass of 3.34×10^{-27} kg and a charge of $+e$. The deuteron travels in a circular path with a radius of 6.96 mm in a magnetic field with magnitude 2.50 T.
    (a) Find the speed of the deuteron.
    (b) Find the time required for it to make $\frac{1}{2}$ of a revolution.
    (c) Through what potential difference would the deuteron have to be accelerated to acquire this speed?

11. A neutral particle is at rest in a uniform magnetic field $\vec{\mathbf{B}}$. At time $t=0$ it decays into two charged particles, each of mass m.
    (a) If the charge of one of the particles is $+q$, what is the charge of the other?
    (b) The two particles move off in separate paths, both of them lie in the plane perpendicular to $\vec{\mathbf{B}}$. At a later time the particles collide. Express the time from decay until collision in terms of m, B and q.

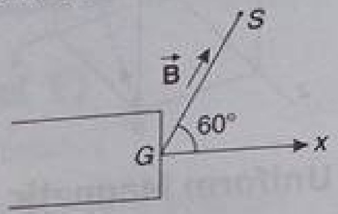
12. An electron at point A in figure has a speed $v_0 = 1.41\times 10^6$ m/s. Find



    (a) the magnitude and direction of the magnetic field that will cause the electron to follow the semicircular path from A to B,
    (b) the time required for the electron to move from A to B.

13. A proton of charge e and mass m enters a uniform magnetic field $\vec{\mathbf{B}} = B\hat{\mathbf{i}}$ with an initial velocity $\vec{\mathbf{v}} = v_x\hat{\mathbf{i}} + v_y\hat{\mathbf{j}}$. Find an expression in unit-vector notation for its velocity at time t.

14. An electron gun G emits electrons of energy 2 keV travelling in the positive x-direction. The electrons are required to hit the spot of S where $GS = 0.1$ m, and the line GS makes an angle of 60° with the x-axis as shown in figure. A uniform magnetic field $\vec{B}$ parallel to GS exists in the region outside the electron gun. Find the minimum value of B needed to make the electron hit S.



15. The region between $x = 0$ and $x = L$ is filled with uniform steady magnetic field $B_0\hat{k}$. A particle of mass m, positive charge q and velocity $v_0\hat{i}$ travels along x-axis and enters the region of the magnetic field.

Neglect the gravity throughout the question.

(a) Find the value of L if the particle emerges from the region of magnetic field with its final velocity at an angle 30° to its initial velocity.

(b) Find the final velocity of the particle and the time spent by it in the magnetic field, if the magnetic field now extends upto 2.1 L.

Motion of Charged Particle in Electric and Magnetic Field

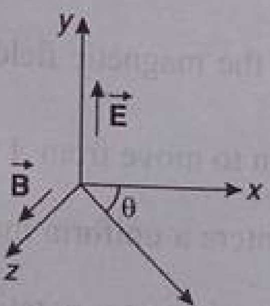
16. A proton moves at a constant velocity of +50 m/s along the x-axis, in uniform electric and magnetic fields. The magnetic field is $\vec{B} = (2.0\text{ mT})\hat{j}$. What is the electric field?

17. A particle having mass m and charge q is released from the origin in a region in which electric field and magnetic field are given by

$$\vec{B} = -B_0\hat{j} \quad \text{and} \quad \vec{E} = E_0\hat{k}$$

Find the components of the velocity and the speed of the particle as a function of its z-coordinate.

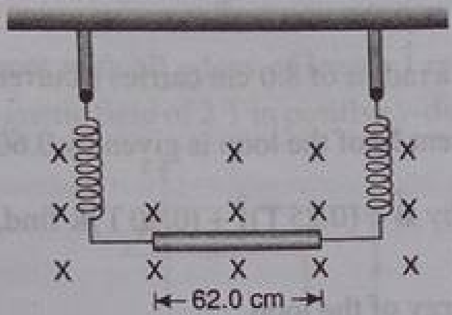
18. Protons move rectillinearly in the region of space where there are uniform mutually perpendicular electric and magnetic fields E and B. The trajectory of protons lies in the plane xz as shown in the figure and forms an angle θ with x-axis. Find the pitch of the helical trajectory along which the protons will move after the electric field is switched off.



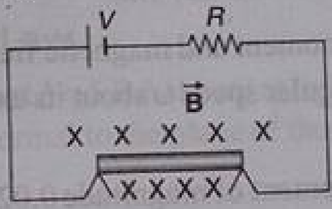
Magnetic Force on Current Carrying Wire

19. A horizontal rod 0.200 m long is mounted on a balance and carries a current. At the location of the rod a uniform horizontal magnetic field has magnitude 0.067 T and direction perpendicular to the rod. The magnetic force on the rod is measured by the balance and is found to be 0.13 N. What is the current?

20. A wire of 62.0 cm length and 13.0 g mass is suspended by a pair of flexible leads in a uniform magnetic field of magnitude 0.440 T in figure. What are the magnitude and direction of the current required to remove the tension in the supporting leads? Take $g = 10\ \text{m/s}^2$.



21. A thin, 50.0 cm long metal bar with mass 750 g rests on, but is not attached to, two metallic supports in a 0.450 T magnetic field, as shown in figure. A battery and a resistance $R = 25.0\,\Omega$ in series are connected to the supports.

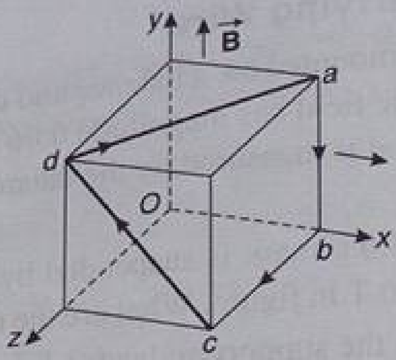


(a) What is the largest voltage the battery can have without breaking the circuit at the supports?
(b) The battery voltage has this maximum value calculated. Decreasing the resistance to $2.0\,\Omega$, find the initial acceleration of the bar.

22. A wire along the x-axis carries a current of 3.50 A in the negative direction. Calculate the force (expressed in terms of unit vectors) on a 1.00 cm section of the wire exerted by these magnetic fields

(a) $\vec{\mathbf{B}} = -(0.65\,\text{T})\hat{\mathbf{j}}$,
(b) $\vec{\mathbf{B}} = +(0.56\,\text{T})\hat{\mathbf{k}}$,
(c) $\vec{\mathbf{B}} = -(0.31\,\text{T})\hat{\mathbf{i}}$,
(d) $\vec{\mathbf{B}} = +(0.33\,\text{T})\hat{\mathbf{i}} - (0.28\,\text{T})\hat{\mathbf{k}}$,
(e) $\vec{\mathbf{B}} = +(0.74\,\text{T})\hat{\mathbf{j}} - (0.36\,\text{T})\hat{\mathbf{k}}$.

23. In figure, the cube is 40.0 cm on each edge. Four straight segments of wire ab, bc, cd and da form a closed loop that carries a current $I = 5.00$ A, in the direction shown. A uniform magnetic field of magnitude $B = 0.020$ T is in the positive y-direction. Determine the magnitude and direction of the magnetic force on each segment.



Magnetic Dipole

24. A circular loop of wire having a radius of 8.0 cm carries a current of 0.20 A. A vector of unit length and parallel to the dipole moment $\vec{M}$ of the loop is given by $0.60\,\hat{i} - 0.80\,\hat{j}$. If the loop is located in uniform magnetic field given by $\vec{B} = (0.25\,T)\hat{i} + (0.30\,T)\hat{k}$ find,
    (a) the torque on the loop and
    (b) the magnetic potential energy of the loop.

25. A length L of wire carries a current i. Show that if the wire is formed into a circular coil, then the maximum torque in a given magnetic field is developed when the coil has one turn only, and that maximum torque has the magnitude $\tau = L^2 iB/4\pi$.

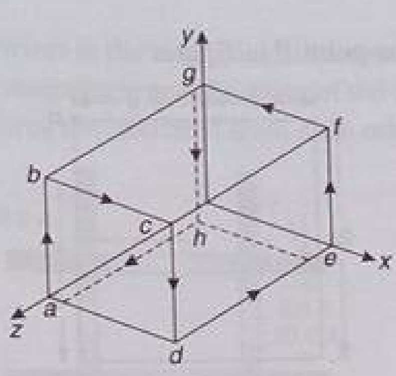
26. Find the ratio of magnetic dipole moment and magnetic field at the centre of a disc. Radius of disc is R and it is rotating at constant angular speed ω about its axis. The disc is insulating and uniformly charged.

27. A magnetic dipole with a dipole moment of magnitude 0.020 J/T is released from rest in a uniform magnetic field of magnitude 52 mT. The rotation of the dipole due to the magnetic force on it is unimpeded. When the dipole rotates through the orientations where its dipole moment is aligned with the magnetic field, its kinetic energy is 0.80 mJ.
    (a) What is the initial angle between the dipole moment and the magnetic field?
    (b) What is the angle when the dipole is next (momentarily) at rest?

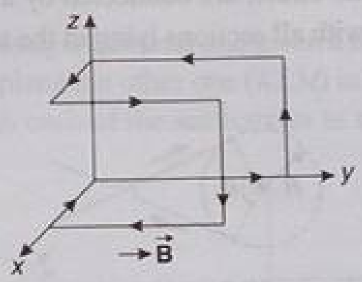
8. A coil with magnetic moment $1.45\ \text{A-m}^2$ is oriented initially with its magnetic moment antiparallel to a uniform 0.835 T magnetic field. What is the change in potential energy of the coil when it is rotated 180° so that its magnetic moment is parallel to the field?

. In the Bohr model of the hydrogen atom, in the lowest energy state the electron revolves round the proton at a speed of 2.2×10^6 m/s in a circular orbit of radius 5.3×10^{-11} m.
    (a) What is the orbital period of the electron?
    (b) If the orbiting electron is considered to be a current loop, what is the current I?
    (c) What is the magnetic moment of the atom due to the motion of the electron?

A conductor carries a constant current I along the closed path *abcdefgha* involving 8 of the 12 edges each of length l. Find the magnetic dipole moment of the closed path.



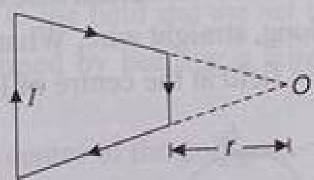
31. Given figure shows a coil bent with all edges of length 1 m and carrying a current of 1 A. There exists in space a uniform magnetic field of 2 T in positive y-direction. Find the torque on the loop.



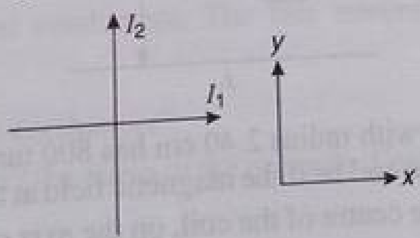
Applications of Biot Savart's Law

32. A very long wire carrying a current $I = 5.0$ A is bent at right angles. Find the magnetic induction at a point lying on a perpendicular normal to the plane of the wire drawn through the point of bending, at a distance $l = 35$ cm from it.

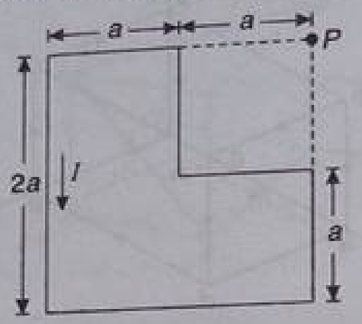
33. A current $I = \sqrt{2}$ A flows in a circuit having the shape of isosceles trapezium. The ratio of the bases of the trapezium is 2. Find the magnetic induction B at symmetric point O in the plane of the trapezium. The length of the smaller base of the trapezium is 100 mm and the distance $r = 50$ mm.



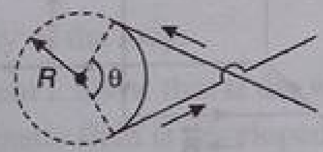
34. Two long mutually perpendicular conductors carrying currents I_1 and I_2 lie in one plane. Find the locus of points at which the magnetic induction is zero.



35. Find the magnetic field $\vec{\mathbf{B}}$ at the point P in figure.



36. A wire carrying current i has the configuration as shown in figure. Two semi-infinite straight sections, both tangent to the same circle, are connected by a circular arc, of central angle θ, along the circumference of the circle, with all sections lying in the same plane. What must θ be for B to be zero at the centre of the circle?



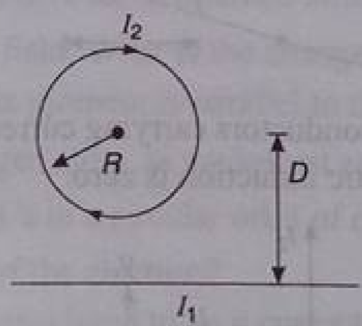
37. Two long parallel transmission lines, 40.0 cm apart, carry 25.0 A and 75.0 A currents. Find all locations where the net magnetic field of the two wires is zero if these currents are in ,

(a) the same direction,

(b) the opposite direction.

38. A closely wound coil has a radius of 6.00 cm and carries a current of 2.50 A. How many turns must it have if, at a point on the coil axis 6.00 cm from the centre of the coil, the magnetic field is 6.39×10^{-4} T?

39. A circular loop of radius R carries current I_2 in a clockwise direction as shown in figure. The centre of the loop is a distance D above a long, straight wire. What are the magnitude and direction of the current I_1 in the wire if the magnetic field at the centre of loop is zero?

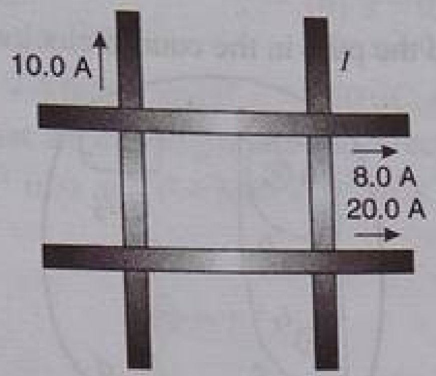


40. A closely wound, circular coil with radius 2.40 cm has 800 turns.

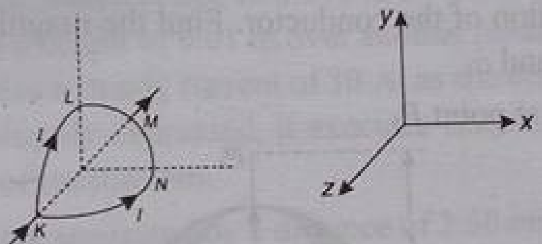
(a) What must the current in the coil be if the magnetic field at the centre of the coil is 0.0580 T?

(b) At what distance x from the centre of the coil, on the axis of the coil, is the magnetic field half its value at the centre?

1. Four very long, current-carrying wires in the same plane intersect to form a square 40.0 cm on each side, as shown in figure. Find the magnitude and direction of the current I so that the magnetic field at the centre of square is zero. Wires are insulated from each other.



42. A circular loop of radius R is bent along a diameter and given a shape as shown in figure. One of the semicircles (KNM) lies in the X-Z plane the other one (KLM) in the Y-Z plane with their centers at origin. Current I is flowing through each of the semicircles as shown in figure.



(a) A particle of charge q is released at the origin with a velocity $\vec{v} = -v_0\hat{i}$. Find the instantaneous force $\vec{F}$ on the particle. Assume that space is gravity free.

(b) If an external uniform magnetic field $B_0\hat{j}$ is applied, determine the force $\vec{F_1}$ and $\vec{F_2}$ on the semicircles KLM and KNM due to the field and the net force $\vec{F}$ on the loop.

43. A regular polygon of n sides is formed by bending a wire of total length $2\pi r$ which carries a current i.

(a) Find the magnetic field B at the centre of the polygon.

(b) By letting $n \to \infty$, deduce the expression for the magnetic field at the centre of a circular coil.

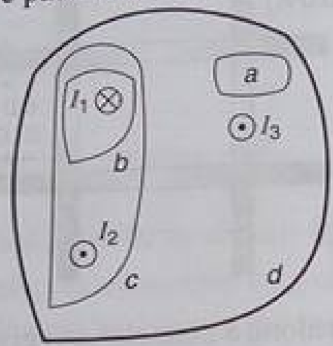
Ampere's Circuital Law

44. A closed curve encircles several conductors. The line integral $\int \vec{B} \cdot d\vec{l}$ around this curve is 3.83×10^{-7} T-m.

(a) What is the net current in the conductors?

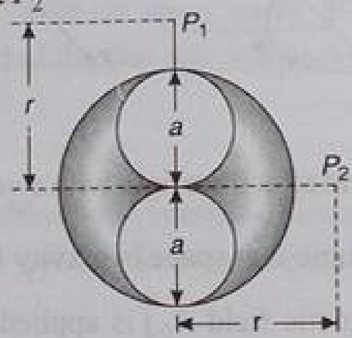
(b) If you were to integrate around the curve in the opposite direction, what would be the value of the line integral?

45. Figure shows, in cross section, several conductors that carry currents through the plane of the figure. The currents have the magnitudes $I_1 = 4.0$ A, $I_2 = 6.0$ A, and $I_3 = 2.0$ A, in the directions shown. Four paths labelled a to d, are shown. What is the line integral $\int \vec{B} \cdot d\vec{l}$ for each path? Each integral involves going around the path in the counterclockwise direction.

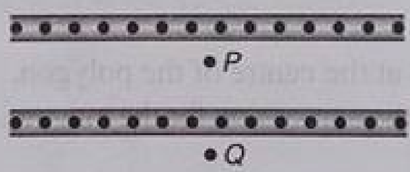


46. A long cylindrical conductor of radius a has two cylindrical cavities of diameter a through its entire length as shown in cross-section in figure. A curent I is directed out of the page and is uniform throughout the cross-section of the conductor. Find the magnitude and direction of the magnetic field in terms of μ_0, I, r and a.

(a) at point P_1 and (b) at point P_2



47. The two infinite plates shown in cross-section in figure carry λ amperes of current out of the page per unit width of plate. Find the magnetic field at points P and Q.



Magnetic Field Due to a Moving Charge, Magnetic Force Between Two Moving Charges and Magnetic Force Between Two Current Carrying Wires

48. A $+6.00\ \mu C$ point charge is moving at a constant velocity 8.00×10^6 m/s in the $+y$ direction. At the instant when the point charge is at the origin of this reference frame, what is the magnetic field vector $\vec{B}$, it produces at the following points.

(a) $x = 0.500$ m, $y = 0$, $z = 0$,

(b) $x = 0$, $y = -0.500$ m, $z = 0$,

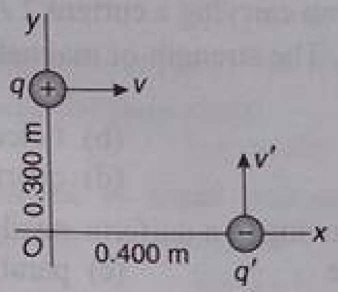
(c) $x = 0$, $y = 0$, $z = +0.500$ m,

(d) $x = 0$, $y = -0.500$ m, $z = +0.500$ m?

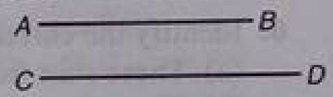
49. A $-4.80\,\mu C$ charge is moving at a constant velocity of 6.80×10^5 m/s in the $+x$ direction relative to a reference frame. At the instant when the point charge is at the origin, what is the magnetic field vector it produces at the following points

(a) $x = 0.500$ m, $y = 0$, $z = 0$,
(b) $x = 0$, $y = 0.500$ m, $z = 0$,
(c) $x = 0.500$ m, $y = 0.500$ m, $z = 0$,
(d) $x = 0$, $y = 0$, $z = 0.500$ m?

50. A pair of point charges, $q = +4.00\,\mu C$ and $q' = -1.50\,\mu C$, are moving in a reference frame as shown in figure. At this instant, what are the magnitude and direction of the magnetic field produced at the origin? (Take $v = 2.00 \times 10^5$ m/s and $v' = 8.00 \times 10^5$ m/s.)



51. A long horizontal wire AB, which is free to move in a vertical plane and carries a steady current of 20 A, is in equilibrium at a height of 0.01 m over another parallel long wire CD which is fixed in a horizontal plane and carries a steady current of 30 A, as shown in figure. Show that when AB is slightly depressed, it executes simple harmonic motion. Find the period of oscillations.

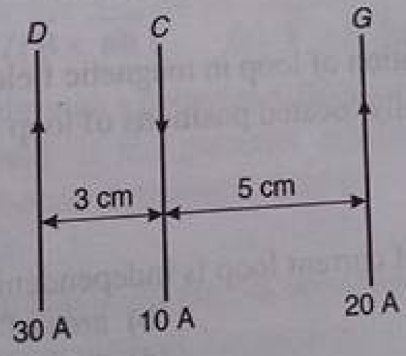


52. Two long parallel wires are separated by a distance of 2.50 cm. The force per unit length that each wire exerts on the other is 4.00×10^{-5} N/m, and the wires repel each other. The current in one wire is 0.600 A.

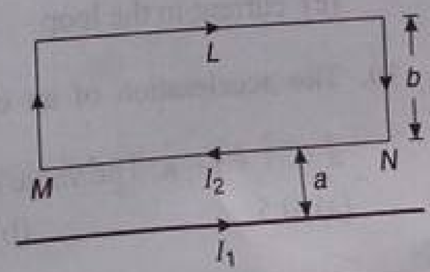
(a) What is the current in the second wire?

(b) Are the two currents in the same direction or in opposite directions?

53. Consider the three long, straight, parallel wires as shown in figure. Find the force experienced by a 25 cm length of wire C.



54. For the situation shown in figure, find the force experienced by side MN of the rectangular loop. Also find the torque on the loop.



Objective Questions (Level 1)

Single Correct Option

1. The universal property among all substances is
(a) diamagnetism (b) paramagnetism (c) ferromagnetism (d) non-magnetism

2. A charged particle moves in a circular path in a uniform magnetic field. If its speed is reduced then its time period will
(a) increase (b) decrease (c) remain same (d) None

3. A straight wire of diameter 0.5 mm carrying a current 2 A is replaced by another wire of diameter 1 mm carrying the same current. The strength of magnetic field at a distance 2 m away from the centre is
(a) half of the previous value (b) twice of the previous value
(c) unchanged (d) quarter of its previous value

4. The path of a charged particle moving in a uniform steady magnetic field cannot be a
(a) straight line (b) circle (c) parabola (d) none of these

5. The SI unit of magnetic permeability is
(a) $Wb\, m^{-2} A^{-1}$ (b) $Wb\, m^{-1} A$ (c) $Wb\, m^{-1} A^{-1}$ (d) $Wb\, m\, A^{-1}$

6. Identify the correct statement about the magnetic field lines
(a) These start from the N-pole and terminate on the S-pole
(b) These lines always form closed loops
(c) both (a) and (b) are correct
(d) both (a) and (b) are wrong

7. Identify the correct statement related to the direction of magnetic moment of a planar loop
(a) It is always perpendicular to the plane of the loop
(b) It depends on the direction of current
(c) It is obtained by right hand screw rule
(d) All of the above

8. A non-planar closed loop of arbitrary shape carrying a current I is placed in uniform magnetic field. The force acting on the loop
(a) is zero only for one orientation of loop in magnetic field
(b) is zero for two symmetrically located positions of loop in magnetic field
(c) is zero for all orientations
(d) is never zero

9. The magnetic dipole moment of current loop is independent of
(a) number of turns (b) area of loop
(c) current in the loop (d) magnetic field in which it is lying

10. The acceleration of an electron at a certain moment in a magnetic field $\vec{B} = 2\hat{i} + 3\hat{j} + 4\hat{k}$ is $\vec{a} = x\hat{i} + \hat{j} - \hat{k}$. The value of x is
(a) 0.5 (b) 1 (c) 2.5 (d) 1.5

11. Match the following and select the correct alternatives given below

(p) unit of magnetic induction B	(q) dimensions of B
(r) unit of permeability (μ_0)	(s) dimensions of μ_0
(t) dimensions of magnetic moment	(u) $[MLT^{-2}A^{-2}]$
(v) $[ML^0T^{-2}A^{-1}]$	(x) Newton/amp-metre
(y) Newton/amp^2	(z) $[M^0L^2T^0A]$

(a) p-y, q-v, r-x, s-z, t-u (b) p-x, q-r, r-y, s-z, t-v
(c) p-x, q-v,. r-y, s-u, t-z (d) p-y, q-z, r-x, s-u, t-v

12. A closed loop carrying a current I lies in the xz plane. The loop will experience a force if it is placed in a region occupied by uniform magnetic field along
(a) x-axis (b) y-axis (c) z-axis (d) None of these

13. A stream of protons and α-particles of equal momenta enter a uniform magnetic field perpendicularly. The radii of their orbits are in the ratio
(a) 1 : 1 (b) 1 : 2 (c) 2 : 1 (d) 4 : 1

14. A loop of magnetic moment $\vec{\mathbf{M}}$ is placed in the orientation of unstable equilibrium position in uniform magnetic field $\vec{\mathbf{B}}$. The external work done in rotating it through an angle θ is
(a) $-MB(1-\cos\theta)$ (b) $-MB(\cos\theta)$ (c) $MB\cos\theta$ (d) $MB(1-\cos\theta)$

15. A current of 50 A is passed through a straight wire of length 6 cm, then the magnetic induction at a point 5 cm from the either end of the wire is (1 gauss $=10^{-4}$T)
(a) 2.5 gauss (b) 1.25 gauss (c) 1.5 gauss (d) 3.0 gauss

16. The magnetic field due to a current carrying circular loop of radius 3 m at a point on the axis at a distance of 4 m from the centre is 54 μT. What will be its value at the centre of the loop?
(a) 250 μT (b) 150 μT (c) 125 μT (d) 75 μT

17. A conductor ab of arbitrary shape carries current I flowing from b to a. The length vector $\overrightarrow{\mathbf{ab}}$ is oriented from a to b. The force $\vec{\mathbf{F}}$ experienced by this conductor in a uniform magnetic field $\vec{\mathbf{B}}$ is
(a) $\vec{\mathbf{F}}=-I(\overrightarrow{\mathbf{ab}}\times\vec{\mathbf{B}})$ (b) $\vec{\mathbf{F}}=I(\vec{\mathbf{B}}\times\overrightarrow{\mathbf{ab}})$ (c) $\vec{\mathbf{F}}=I(\overrightarrow{\mathbf{ba}}\times\vec{\mathbf{B}})$ (d) All of these

18. When an electron is accelerated through a potential difference V, it experiences a force F through a uniform transverse magnetic field. If the potential difference is increased to 2 V, the force experienced by the electron in the same magnetic field is
(a) $2F$ (b) $2\sqrt{2}F$ (c) $\sqrt{2}F$ (d) $4F$

19. Two long straight wires, each carrying a current I in opposite directions are separated by a distance R. The magnetic induction at a point midway between the wires is
(a) zero (b) $\frac{\mu_0 I}{\pi R}$ (c) $\frac{2\mu_0 I}{\pi R}$ (d) $\frac{\mu_0 I}{4\pi R}$

20. The magnetic field at a distance x on the axis of a circular coil of radius R is $\frac{1}{8}$th of that at the centre. The value of x is

(a) $\frac{R}{\sqrt{3}}$ (b) $\frac{2R}{\sqrt{3}}$ (c) $R\sqrt{3}$ (d) $R\sqrt{2}$

21. Electric field and magnetic field in a region of space is given by $\vec{\mathbf{E}} = E_0\hat{\mathbf{j}}$ and $\vec{\mathbf{B}} = B_0\hat{\mathbf{j}}$. A particle of specific charge α is released from origin with velocity $\vec{\mathbf{v}} = v_0\hat{\mathbf{i}}$. Then path of particle

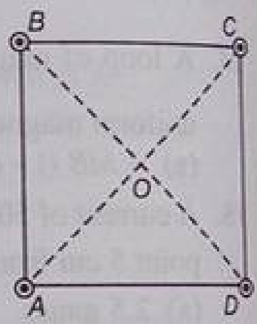
(a) is a circle
(b) is a helix with uniform pitch
(c) is a helix with non-uniform pitch
(d) is cycloid

Note *E_0, B_0 and v_0 are constant values.*

22. An electron having kinetic energy K is moving in a circular orbit of radius R perpendicular to a uniform magnetic induction. If kinetic energy is doubled and magnetic induction tripled, the radius will become

(a) $\frac{2R}{3}$ (b) $\frac{\sqrt{2}}{3}R$ (c) $\sqrt{\frac{2}{3}}R$ (d) $\frac{2}{\sqrt{3}}R$

23. Four long straight wires are located at the corners of a square $ABCD$. All the wires carry equal currents. Current in the wires A and B are inwards and in C and D are outwards. The magnetic field at the centre O is along

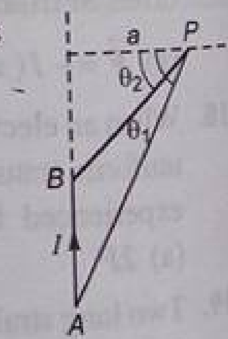


(a) AD
(b) CB
(c) AB
(d) CD

24. A charged particle of mass m and charge q is accelerated through a potential difference of V volts. It enters a region of uniform magnetic field B which is directed perpendicular to the direction of motion of the particle. The particle will move on a circular path of radius

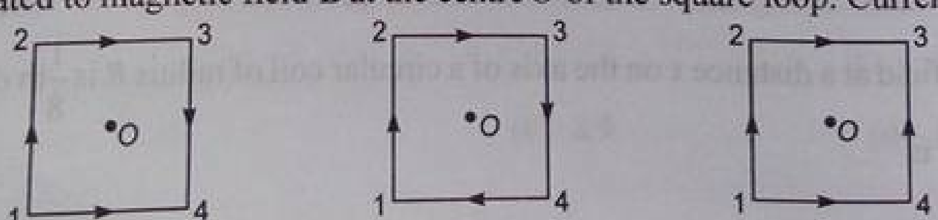
(a) $\sqrt{\frac{Vm}{2qB^2}}$ (b) $\frac{2Vm}{qB^2}$ (c) $\sqrt{\frac{2Vm}{q}}\left(\frac{1}{B}\right)$ (d) $\sqrt{\frac{Vm}{q}}\left(\frac{1}{B}\right)$

25. The straight wire AB carries a current I. The ends of the wire subtend angles θ_1 and θ_2 at the point P as shown in figure. The magnetic field at the point P is



(a) $\frac{\mu_0 I}{4\pi a}(\sin\theta_1 - \sin\theta_2)$
(b) $\frac{\mu_0 I}{4\pi a}(\sin\theta_1 + \sin\theta_2)$
(c) $\frac{\mu_0 I}{4\pi a}(\cos\theta_1 - \cos\theta_1)$
(d) $\frac{\mu_0 I}{4\pi a}(\cos\theta_1 + \cos\theta_2)$

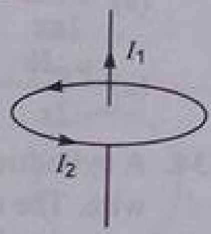
26. The figure shows three identical current carrying square loops A, B and C. Identify the correct statement related to magnetic field $\vec{\mathbf{B}}$ at the centre O of the square loop. Current in each wire is I.



(A) (B) (C)

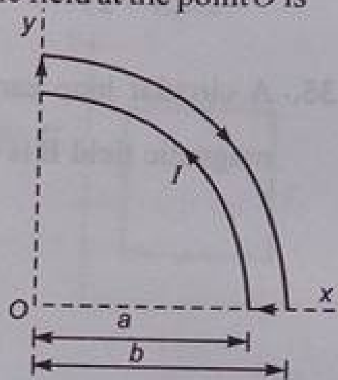
(a) $\vec{B}$ is zero in all cases
(b) $\vec{B}$ is zero only in case of C
(c) $\vec{B}$ in non-zero in all cases
(d) $\vec{B}$ is non-zero only in case of B

27. The figure shows a long straight wire carrying a current I_1 along the axis of a circular ring carrying a current I_2. Identify the correct statement



(a) Straight wire attracts the ring
(b) Straight wire attracts a small element of the ring
(c) Straight wire does not attract any small element of the ring
(d) None of these

28. The figure shows a wire frame is xy plane carrying a current I. The magnetic field at the point O is



(a) $\frac{\mu_0 I}{8}\left[\frac{1}{a}-\frac{1}{b}\right]\hat{k}$
(b) $\frac{\mu_0 I}{8}\left[\frac{1}{b}-\frac{1}{a}\right]\hat{k}$
(c) $\frac{\mu_0 I}{4}\left[\frac{1}{a}-\frac{1}{b}\right]\hat{k}$
(d) $\frac{\mu_0 I}{4}\left[\frac{1}{b}-\frac{1}{a}\right]\hat{k}$

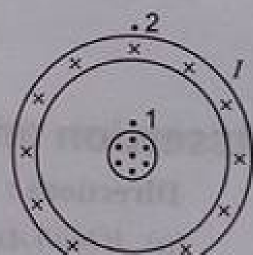
29. An electron moving in a circular orbit of radius R with frequency f. The magnetic field at the centre of the orbit is

(a) $\frac{\mu_0 ef}{2\pi R}$ (b) $\frac{\mu_0 ef}{2R}$ (c) $\frac{\mu ef^2}{2R}$ (d) zero

30. A square loop of side 'a' carries a current I. The magnetic field at the centre of the loop is

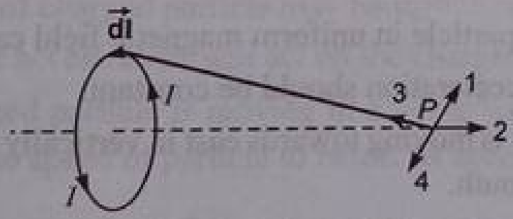
(a) $\frac{2\mu_0 I\sqrt{2}}{\pi a}$ (b) $\frac{\mu_0 I\sqrt{2}}{\pi a}$ (c) $\frac{4\mu_0 I\sqrt{2}}{\pi a}$ (d) $\frac{\mu_0 I}{\pi a}$

31. The figure shows the cross-section of two long coaxial tubes carrying equal currents I in opposite directions. If B_1 and B_2 are magnetic fields at points 1 and 2, as shown in figure then



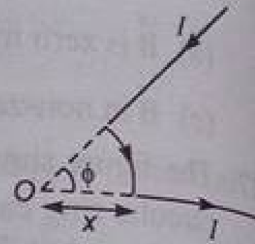
(a) $B_1 \neq 0; B_2 = 0$
(b) $B_1 = 0; B_2 = 0$
(c) $B_1 \neq 0; B_2 \neq 0$
(d) $B_1 = 0, B_2 \neq 0$

32. The figure shows a point P on the axis of a circular loop carrying current I. The correct direction of magnetic field vector at P due to $d\vec{l}$ is represented by



(a) 1 (b) 2 (c) 3 (d) 4

33. In figure the curved part represents arc of a circle of radius x. If it carries a current I, then the magnetic field at the point O is



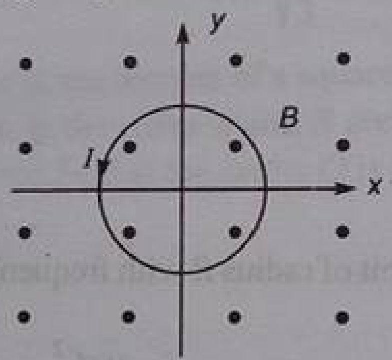
(a) $\frac{\mu_0 I\phi}{2\pi x}$ (b) $\frac{\mu_0 I\phi}{4\pi x}$

(c) $\frac{\mu_0 I\phi}{2x}$ (d) $\frac{\mu_0 I\phi}{4x}$

34. A cylindrical long wire carries a current I uniformly distributed over the cross-sectional area of the wire. The magnetic field at a distance x from the surface inside the wire is

(a) $\frac{\mu_0 I}{2\pi(R-x)}$ (b) $\frac{\mu_0 I}{2\pi x}$ (c) $\frac{\mu_0 I}{2\pi(R+x)}$ (d) None of these

35. A circular loop carrying a current I is placed in the xy plane as shown in figure. An uniform magnetic field $\vec{\mathbf{B}}$ is oriented along the positive Z-axis. The loop tends to



(a) expand (b) contract

(c) rotate about x-axis (d) rotate about y-axis

JEE Corner

Assertion and Reason

Directions : *Choose the correct option.*

(a) *If both **Assertion** and **Reason** are true and the **Reason** is correct explanation of the **Assertion**.*

(b) *If both **Assertion** and **Reason** are true but **Reason** is not the correct explanation of **Assertion**.*

(c) *If **Assertion** is true, but the **Reason** is false.*

(d) *If **Assertion** is false but the **Reason** is true.*

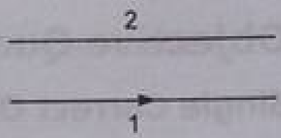
1. Assertion : Path of a charged particle in uniform magnetic field can't be a parabola.

Reason : For parabolic path acceleration should be constant.

2. Assertion : A beam of protons is moving towards east in vertically upward magnetic field. The this beam will deflect towards south.

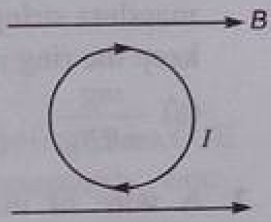
Reason : A constant magnetic force will act on the proton beam.

3. **Assertion :** Current in wire-1 is in the direction as shown in figure. The bottom wire is fixed. To keep the upper wire stationary current in it should be in opposite direction.

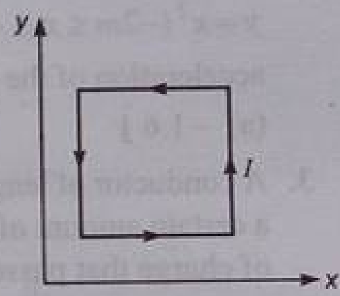


Reason : Under the above condition, equilibrium of upper wire is stable.

4. **Assertion :** A current carrying loop is placed in uniform magnetic field as shown in figure. Torque in the loop in this case is zero.



Reason : Magnetic moment vector of the loop is perpendicular to paper inwards.



5. **Assertion :** Force on current carrying loop shown in figure in magnetic field, $\vec{B} = (B_0 x)\hat{k}$ is along positive x-axis.

Here B_0 is a positive constant.

Reason : A torque will also act on the loop.

6. **Assertion :** An electron and a proton are accelerated by same potential difference and then enter in uniform transverse magnetic field. The radii of the two will be different.

Reason : Charges on them are different.

7. **Assertion :** A charged particle moves along positive y-axis with constant velocity in uniform electric and magnetic fields. If magnetic field is acting along positive x-axis, then electric field should act along positive z-axis.

Reason : To keep the charged particle undeviated the relation $\vec{E} = \vec{B} \times \vec{v}$ must hold good.

8. **Assertion :** Power of a magnetic force on a charged particle is always zero.

Reason : Power of electric force on charged particle can't be zero.

9. **Assertion :** If a charged particle enters from outside at right angles in uniform magnetic field. The maximum time spent in magnetic field may be $\dfrac{\pi m}{Bq}$.

Reason : It can complete only semi-circle in the magnetic field.

10. **Assertion :** A charged particle enters in a magnetic field $\vec{B} = B_0\hat{i}$ with velocity $\vec{v} = v_0\hat{i} + v_0\hat{j}$, then minimum speed of charged particle may be v_0.

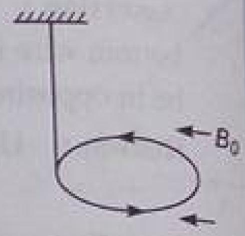
Reason : A variable acceleration will act on the charged particle.

11. **Assertion :** A charged particle is moving in a circle with constant speed in uniform magnetic field. If we increase the speed of particle to twice, its acceleration will become four times.

Reason : In circular path of radius R with constant speed v, acceleration is given by $\dfrac{v^2}{R}$.

Objective Questions (Level 2)

Single Correct Option



1. A uniform current carrying ring of mass m and radius R is connected by a massless string as shown. A uniform magnetic field B_0 exist in the region to keep the ring in horizontal position, then the current in the ring is

(a) $\frac{mg}{\pi R B_0}$ (b) $\frac{mg}{R B_0}$ (c) $\frac{mg}{3\pi R B_0}$ (d) $\frac{mg}{\pi R^2 B_0}$

2. A wire of mass 100 g is carrying a current of 2 A towards increasing x in the form of $y = x^2 (-2m \le x \le +2m)$. This wire is placed in a magnetic field $\vec{\mathbf{B}} = -0.02\,\hat{\mathbf{k}}$ tesla. The acceleration of the wire (in m/s^2) is

(a) $-1.6\,\hat{\mathbf{j}}$ (b) $-3.2\,\hat{\mathbf{j}}$ (c) $1.6\,\hat{\mathbf{j}}$ (d) zero

3. A conductor of length l is placed perpendicular to a horizontal uniform magnetic field B. Suddenly a certain amount of charge is passed through it, when it is found to jump to a height h. The amount of charge that passes through the conductor is

(a) $\frac{m\sqrt{gh}}{Bl}$ (b) $\frac{m\sqrt{gh}}{2Bl}$ (c) $\frac{m\sqrt{2gh}}{Bl}$ (d) None of these

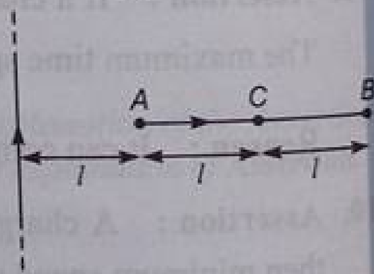
4. A solid conducting sphere of radius R and total charge q rotates about its diametric axis with constant angular speed ω. The magnetic moment of the sphere is

(a) $\frac{1}{3} qR^2\omega$ (b) $\frac{2}{3} qR^2\omega$ (c) $\frac{1}{5} qR^2\omega$ (d) $\frac{2}{5} qR^2\omega$

5. A charged particle moving along positive x-direction with a velocity v enters a region where there is a uniform magnetic field $\vec{\mathbf{B}} = -B\,\hat{\mathbf{k}}$, from $x = 0$ to $x = d$. The particle gets deflected at an angle θ from its initial path. The specific charge of the particle is

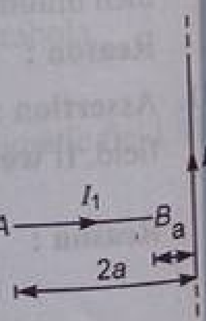
(a) $\frac{Bd}{v\cos\theta}$ (b) $\frac{v\tan\theta}{Bd}$ (c) $\frac{B\sin\theta}{vd}$ (d) $\frac{v\sin\theta}{Bd}$

6. A current carrying rod AB is placed perpendicular to an infinitely long current carrying wire as shown in figure. The point at which the conductor should be hinged so that it will not rotate ($AC = CB$)



(a) A (b) some where between B and C
(c) C (d) some where between A and C

7. The segment AB of wire carrying current I_1 is placed perpendicular to a long straight wire carrying current I_2 as shown in figure. The magnitude of force experienced by the straight wire AB is

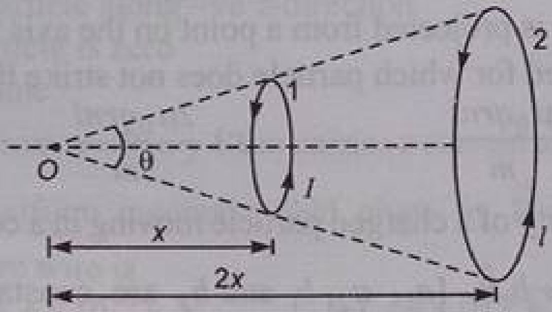


(a) $\frac{\mu_0 I_1 I_2}{2\pi} \ln 3$ (b) $\frac{\mu_0 I_1 I_2}{2\pi} \ln 2$

(c) $\frac{2\mu_0 I_1 I_2}{2\pi}$ (d) $\frac{\mu_0 I_1 I_2}{2\pi}$

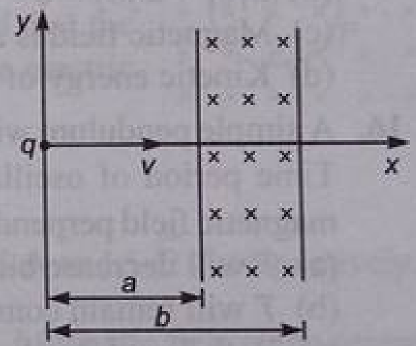
8. A straight long conductor carries current along the positive x-axis. Identify the correct statement related to the four points $A(a, a, 0)$, $B(a, 0, a)$, $C(a, -a, 0)$ and $D(a, 0, -a)$
(a) The magnitude of magnetic field at all points is same
(b) Fields at A and B are mutually perpendicular
(c) Fields at A and C are antiparallel
(d) All of the above

9. The figure shows two coaxial circular loops 1 and 2, which forms same solid angle θ at point O. If B_1 and B_2 are the magnetic fields produced at the point O due to loop 1 and 2 respectively, then



(a) $\frac{B_1}{B_2} = 1$ (b) $\frac{B_1}{B_2} = 2$ (c) $\frac{B_1}{B_2} = 8$ (d) $\frac{B_1}{B_2} = 4$

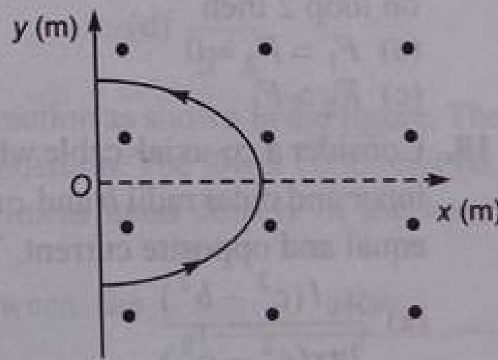
10. In the figure shown, a charge q moving with a velocity v along the x-axis enter into a region of uniform magnetic field. The minimum value of v so that the charge q is able to enter the region $x > b$



(a) $\frac{qBb}{m}$ (b) $\frac{qBa}{m}$
(c) $\frac{qB(b-a)}{m}$ (d) $\frac{qB(b+a)}{2m}$

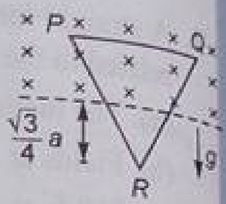
11. An insulating rod of length l carries a charge q uniformly distributed on it. The rod is pivoted at one of its ends and is rotated at a frequency f about a fixed perpendicular axis. The magnetic moment of the rod is
(a) $\frac{\pi q f l^2}{12}$ (b) $\frac{\pi q f l^2}{2}$ (c) $\frac{\pi q f l^2}{6}$ (d) $\frac{\pi q f l^2}{3}$

12. A wire carrying a current of 3 A is bent in the form of a parabola $y^2 = 4 - x$ as shown in figure, where x and y are in metre. The wire is placed in a uniform magnetic field $\vec{B} = 5\hat{k}$ tesla. The force acting on the wire is



(a) $60\,\hat{i}$ N
(b) $-60\hat{i}$ N
(c) $30\,\hat{i}$ N
(d) $-30\,\hat{i}$ N

13. An equilateral triangle frame PQR of mass M and side a is kept under the influence of magnetic force due to inward perpendicular magnetic field B and gravitational field as shown in the figure. The magnitude and direction of current in the frame so that the frame remains at rest is



(a) $I = \dfrac{2Mg}{aB}$, anticlockwise (b) $I = \dfrac{2Mg}{aB}$; clockwise

(c) $I = \dfrac{Mg}{aB}$, anticlockwise (d) $I = \dfrac{Mg}{aB}$, clockwise

14. A tightly-wound long selenoid has n turns per unit length, radius r and carries a current i. A particle having charge q and mass m is projected from a point on the axis in the direction perpendicular to the axis. The maximum speed for which particle does not strike the solenoid will be

(a) $\dfrac{\mu_0 qrni}{2m}$ (b) $\dfrac{\mu_0 qrni}{m}$ (c) $\dfrac{2\mu_0 qrni}{3m}$ (d) None of these

15. If the acceleration and velocity of a charged particle moving in a constant magnetic region is given by $\vec{\mathbf{a}} = a_1\hat{\mathbf{i}} + a_2\hat{\mathbf{k}}$, $\vec{\mathbf{v}} = b_1\hat{\mathbf{i}} + b_2\hat{\mathbf{k}}$. [$a_1$, a_2, b_1 and b_2 are constants]. Then choose the **wrong** statement

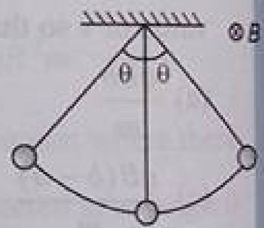
(a) Magnetic field may be along y-axis

(b) $a_1 b_1 + a_2 b_2 = 0$

(c) Magnetic field is along x-axis

(d) Kinetic energy of particle is always constant

16. A simple pendulum with a charged bob is oscillating as shown in the figure. Time period of oscillation is T and angular amplitude is θ. If a uniform magnetic field perpendicular to the plane of oscillation is switched on, then



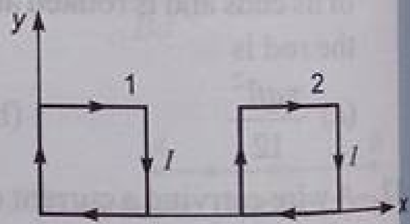
(a) T will decrease but θ will remain constant

(b) T will remain constant but θ will decrease

(c) Both T and θ will remain the same

(d) Both T and θ will decrease

17. Magnetic field in a region is given by $\vec{\mathbf{B}} = B_0 x\hat{\mathbf{k}}$. Two loops each of side a is placed in this magnetic region in the x-y plane with one of its sides on x-axis. If F_1 is the force on loop 1 and F_2 be the force on loop 2 then



(a) $F_1 = F_2 = 0$ (b) $F_1 > F_2$

(c) $F_2 > F_1$ (d) $F_1 = F_2 \neq 0$

18. Consider a co-axial cable which consists of an inner wire of radius a surrounded by an outer shell of inner and outer radii b and c respectively. The inner wire carries a current I and outer shell carries an equal and opposite current. The magnetic field at a distance x from the axis where $b < x < c$ is

(a) $\dfrac{\mu_0 I(c^2 - b^2)}{2\pi x(c^2 - a^2)}$ (b) $\dfrac{\mu_0 I(c^2 - x^2)}{2\pi x(c^2 - a^2)}$

(c) $\dfrac{\mu_0 I(c^2 - x^2)}{2\pi x(c^2 - b^2)}$ (d) zero

19. A particle of mass 1×10^{-26} kg and charge $+1.6 \times 10^{-19}$ C travelling with a velocity of 1.28×10^{6} m/s along positive direction of x-axis enters a region in which a uniform electric field $\vec{E}$ and a uniform magnetic field $\vec{B}$ are present such that

$$E_z = -102.4 \text{ kV/m}$$

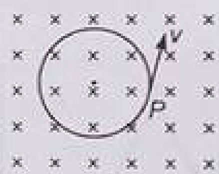
and

$$B_y = 8 \times 10^{-2} \text{ Wb/m}^2$$

The particle enters this region at origin at time $t = 0$. Then
(a) net force acts on the particle along the +ve z-direction
(b) net force acts on the particle along –ve z-direction
(c) net force acting on particle is zero
(d) net force acts in x-z plane

20. A wire lying along y-axis from $y = 0$ to $y = 1$ m carries a current of 2 mA in the negative y-direction. The wire lies in a non-uniform magnetic field given by $\vec{B} = (0.3 \text{ T/m})\, y\hat{i} + (0.4 \text{ Tm})\, y\hat{j}$. The magnetic force on the entire wire is
(a) $-3 \times 10^{-4}\, \hat{j}$ N (b) $6 \times 10^{-3}\, \hat{k}$ N (c) $-3 \times 10^{-4}\, \hat{k}$ N (d) $3 \times 10^{-4}\, \hat{k}$ N

21. A particle having a charge of 20 μC and mass 20 μg moves along a circle of radius 5 cm under the action of a magnetic field $B = 0.1$ tesla. When the particle is at P, uniform transverse electric field is switched on and it is found that the particle continues along the tangent with a uniform velocity. Find the electric field

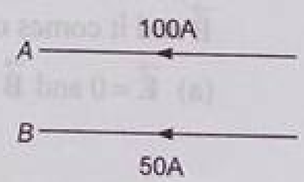


(a) 2 V/m (b) 0.5 V/m
(c) 5 V/m (d) 1.5 V/m

22. Two circular coils A and B of radius $\frac{5}{\sqrt{2}}$ cm and 5 cm carry currents 5 A and $5\sqrt{2}$ A respectively. The plane of B is perpendicular to plane of A and their centres coincide. Magnetic field at the centre is
(a) 0 (b) $4\pi\sqrt{2} \times 10^{-5}$ T (c) $4\pi \times 10^{-5}$ T (d) $2\pi\sqrt{2} \times 10^{-5}$ T

23. A charged particle with specific charge s moves undeflected through a region of space containing mutually perpendicular and uniform electric and magnetic fields E and B. When the electric field is switched off, the particle will move in a circular path of radius
(a) $\frac{E}{Bs}$ (b) $\frac{Es}{B}$ (c) $\frac{Es}{B^2}$ (d) $\frac{E}{B^2 s}$

24. Two long parallel conductors are carrying currents in the same direction as shown in the figure. The upper conductor (A) carrying a current of 100 A is held firmly in position. The lower conductor (B) carries a current of 50 A and free to move up and down. The linear mass density of the lower conductor is 0.01 kg/m
(a) Conductor B will be in equilibrium if the distance between the conductors is 0.1 m
(b) Equilibrium of conductor B is unstable
(c) Both (a) and (b) are wrong
(d) Both (a) and (b) are correct



25. Equal currents are flowing in three infinitely long wires along positive x, y and z directions. The magnetic field at a point $(0, 0, -a)$ would be (i = current in each wire)

(a) $\frac{\mu_0 i}{2\pi a}(\hat{j} - \hat{i})$ (b) $\frac{\mu_0 i}{2\pi a}(\hat{i} - \hat{j})$ (c) $\frac{\mu_0 i}{2\pi a}(\hat{i} + \hat{j})$ (d) $\frac{\mu_0 i}{2\pi a}(-\hat{i} - \hat{j})$

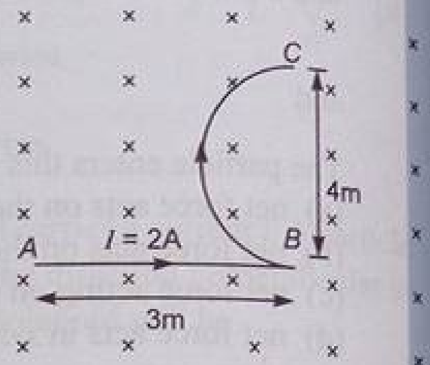
26. In the figure the force on the wire ABC in the given uniform magnetic field will be ($B = 2$ tesla)

(a) $4(3 + 2\pi) Nt$

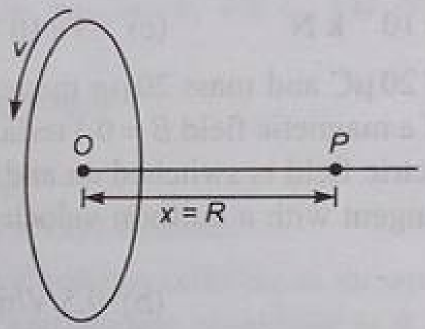
(b) $20\ Nt$

(c) $30 Nt$

(d) $40\ Nt$



27. A uniformly charged ring of radius R is rotated about its axis with constant linear speed v of each of its particles. The ratio of electric field to magnetic field at a point P on the axis of the ring distant $x = R$ from centre of ring is (c is speed of light)



(a) $\frac{c^2}{v}$ (b) $\frac{v^2}{c}$ (c) $\frac{v}{c}$ (d) $\frac{c}{v}$

More than One Correct Options

1. Two circular coils of radii 5 cm and 10 cm carry currents of 2 A. The coils have 50 and 100 turns respectively and are placed in such a way that their planes as well as their centres coincide. Magnitude of magnetic field at the common centre of coils is

(a) $8\pi \times 10^{-4}$ T if currents in the coils are in same sense

(b) $4\pi \times 10^{-4}$ T if currents in the coils are in opposite sense

(c) zero if currents in the coils are in opposite sense

(d) $8\pi \times 10^{-4}$ T if currents in the coils are in opposite sense

2. A charged particle enters into a gravity free space occupied by an electric field $\vec{E}$ and magnetic field $\vec{B}$ and it comes out without any change in velocity. Then the possible cases may be

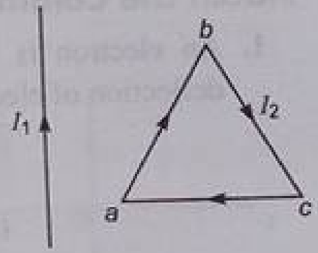
(a) $\vec{E} = 0$ and $\vec{B} \neq 0$ (b) $\vec{E} \neq 0$ and $\vec{B} = 0$ (c) $\vec{E} \neq 0$ and $\vec{B} \neq 0$ (d) $\vec{E} = 0, \vec{B} = 0$

3. A charged particle of unit mass and unit charge moves with velocity $\vec{v} = (8\hat{i} + 6\hat{j})$ m/s in a magnetic field of $\vec{B} = 2\hat{k}$ T. Choose the correct alternative (s).
(a) The path of the particle may be $x^2 + y^2 - 4x - 21 = 0$
(b) The path of the particle may be $x^2 + y^2 = 25$
(c) The path of the particle may be $y^2 + z^2 = 25$
(d) The time period of the particle will be 3.14 s

4. When a current carrying coil is placed in a uniform magnetic field with its magnetic moment anti-parallel to the field
(a) Torque on it is maximum
(b) Torque on it is zero
(c) Potential energy is maximum
(d) Dipole is in unstable equilibrium

5. If a long cylindrical conductor carries a steady current parallel to its length
(a) the electric field along the axis is zero
(b) the magnetic field along the axis is zero
(c) the magnetic field outside the conductor is zero
(d) the electric field outside the conductor is zero

6. An infinitely long straight wire is carrying a current I_1. Adjacent to it there is another equilateral triangular wire having current I_2. Choose the wrong options.



(a) Net force on loop is leftwards
(b) Net force on loop is rightwards
(c) Net force on loop is upwards
(d) Net force on loop is downwards

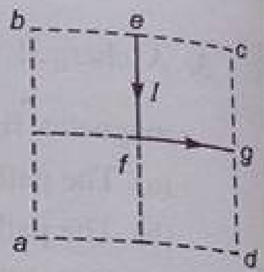
7. A charged particle is moving along positive y-axis in uniform electric and magnetic fields

$$\vec{E} = E_0\hat{k} \quad \text{and} \quad \vec{B} = B_0\hat{i}$$

Here E_0 and B_0 are positive constants. Choose the correct options.
(a) particle may be deflected towards positive z-axis
(b) particle may be deflected towards negative z-axis
(c) particle may pass undeflected
(d) kinetic energy of particle may remain constant

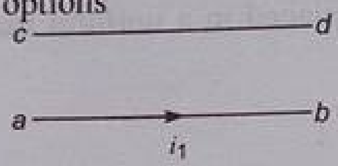
8. A charged particle revolves in circular path in uniform magnetic field after accelerating by a potential difference of V volts. Choose the correct options if V is doubled
(a) kinetic energy of particle will become two times
(b) radius in circular path will become two times
(c) radius in circular path will become $\sqrt{2}$ times
(d) angular velocity will remain unchanged

9. *abcd* is a square. There is a current I in wire *efg* as shown.



Choose the correct options :
(a) Net magnetic field at a is inwards
(b) Net magnetic field at b is zero
(c) Net magnetic field at c is outwards
(d) Net magnetic field at d is inwards

10. There are two wires *ab* and *cd* in a vertical plane as shown in figure. Direction of current in wire *ab* is rightwards. Choose the correct options



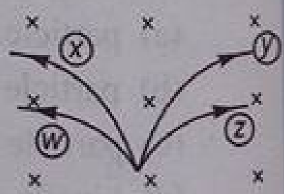
(a) If wire *ab* is fixed then wire *cd* can be kept in equilibrium by the current in *cd* in leftward direction
(b) Equilibrium of wire *cd* will be stable equilibrium
(c) If wire *cd* is fixed, then wire *ab* can be kept in equilibrium by flowing current in *cd* in rightward direction
(d) Equilibrium of wire *ab* will be stable equilibrium

Match the Columns

1. An electron is moving towards positive x-direction. Match the following two columns for deflection of electron just after the fields are switched on. (E_0 and B_0 are positive constants)

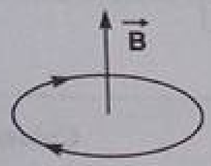
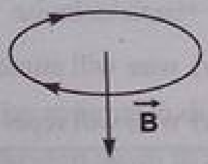
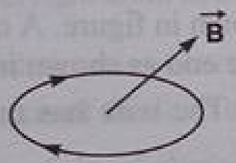
Column I	Column II
(a) If magnetic field $\vec{B} = B_0\hat{j}$ is switched on	(p) Negative y-axis
(b) If magnetic field $\vec{B} = B_0\hat{k}$ is switched on	(q) Positive y-axis
(c) If magnetic field $\vec{B} = B_0\hat{i}$ and electric field $\vec{E} = E_0\hat{j}$ is switched on	(r) Negative z-axis
(d) If electric field $\vec{E} = E_0\hat{k}$ is switched on	(s) Positive z-axis

2. Four charged particles, $(-q, m)$, $(-3q, 4m)$, $(+q, m)$ and $(+3q, 4m)$ enter in uniform magnetic field (in inward direction) with same kinetic energy as shown in figure. Inside the magnetic field their paths are shown. Match the following two columns.

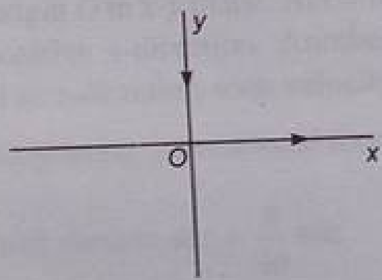


Column I	Column II
(a) Particle $(-q, m)$	(p) w
(b) Particle $(-3q, 4m)$	(q) x
(c) Particle $(+q, m)$	(r) y
(d) Particle $(+3q, 4m)$	(s) z

3. In column I, a current carrying loop and a uniform magnetic field are shown. Match this with column II.

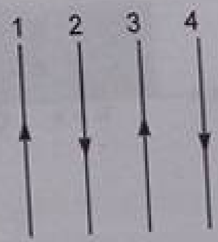
Column I	Column II
(a) 	(p) Force = 0
(b) 	(q) Maximum torque
(c) 	(r) Minimum potential energy
(d) 	(s) Positive potential energy

4. Equal currents are flowing in two infinitely long wires lying along x and y axes in the directions shown in figure. Match the following two columns.



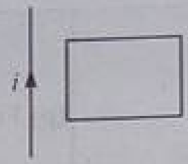
Column I	Column II
(a) Magnetic field at (a, a)	(p) along positive y-axis
(b) Magnetic field at $(-a, -a)$	(q) along positive z-axis
(c) Magnetic field at $(a, -a)$	(r) along negative z-axis
(d) Magnetic field at $(-a, a)$	(s) zero

5. Equal currents are flowing in four infinitely long wires. Distance between two wires is same and directions of currents are shown in figure. Match the following two columns.



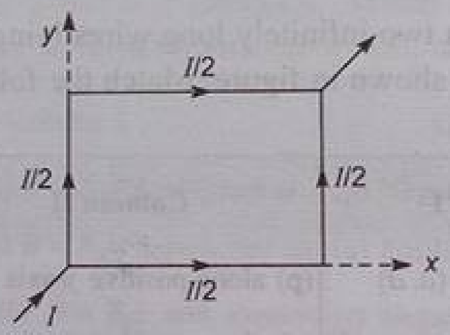
Column I	Column II
(a) Force on wire-1	(p) inwards
(b) Force on wire-2	(q) leftwards
(c) Force on wire-3	(r) rightwards
(d) Force on wire-4	(s) zero

6. A square loop is placed near a long straight current carrying wire as shown. Match the following two columns



Column I	Column II
(a) If current is increased	(p) induced current in loop is clockwise
(b) If current is decreased	(q) induced current in loop is anticlockwise
(c) If loop is moved away from the wire	(r) wire will attract the loop
(d) If loop is moved towards the wire	(s) wire will repel the loop

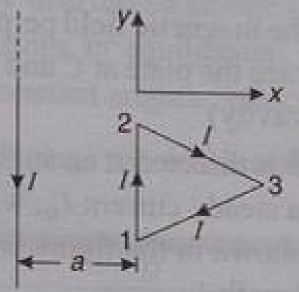
7. A square loop of uniform conducting wire is as shown in figure. A current I (in ampere) enters the loop from one end and exits the loop from opposite end as shown in figure. The length of one side of square loop is l metre. The wire has uniform cross-section area and uniform linear mass density.



Column I	Column II
(a) $\vec{B} = B_0\hat{i}$ in tesla	(p) magnitude of net force on loop is $\sqrt{2}B_0Il$ newton
(b) $\vec{B} = B_0\hat{j}$ in tesla	(q) magnitude of net force on loop is zero
(c) $\vec{B} = B_0(\hat{i} + \hat{j})$ in tesla	(r) magnitude of net torque on loop is zero
(d) $\vec{B} = B_0\hat{k}$ in tesla	(s) magnitude of net force on loop is B_0Il newton

Subjective Questions (Level 2)

1. An equilateral triangular frame with side a carrying a current I is placed at a distance a from an infinitely long straight wire carrying a current I as shown in the figure. One side of the frame is parallel to the wire. The whole system lies in the x-y plane. Find the magnetic force $\vec{F}$ acting on the frame.



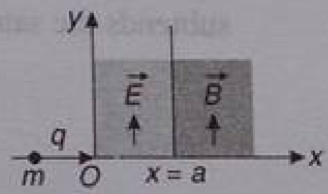
2. Find an expression for the magnetic dipole moment and magnetic field induction at the centre of a Bohr's hypothetical hydrogen atom in the n^{th} orbit of the electron in terms of universal constants.

3. A square loop of side 6 cm carries a current of 30 A. Calculate the magnitude of magnetic field $\vec{B}$ at a point P lying on the axis of the loop and a distance $\sqrt{7}$ cm from centre of the loop.

4. A positively charged particle of charge 1 C and mass 40 g, is revolving along a circle of radius 40 cm with velocity 5 m/s in a uniform magnetic field with centre at origin O in x-y plane. At $t = 0$, the particle was at (0, 0.4 m, 0) and velocity was directed along positive x-direction. Another particle having charge 1 C and mass 10 g moving uniformly parallel to z-direction with velocity $\frac{40}{\pi}$ m/s collides with revolving particle at $t = 0$ and gets stuck with it. Neglecting gravitational force and coulombian force, calculate x, y and z-coordinates of the combined particle at $t = \frac{\pi}{40}$ sec.

5. A proton beam passes without deviation through a region of space where there are uniform transverse mutually perpendicular electric and magnetic fields with $E = 120 \frac{\text{kV}}{\text{m}}$ and $B = 50$ mT. Then, the beam strikes a grounded target. Find the force imparted by the beam on the target if the beam current is equal to $I = 0.80$ mA.

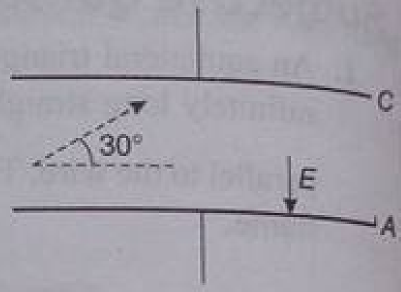
6. A positively charged particle, having charge q, is accelerated by a potential difference V. This particle moving along the x-axis enters a region where an electric field E exists. The direction of the electric field is along positive y-axis. The electric field exists in the region bounded by the lines $x = 0$ and $x = a$. Beyond the line $x = a$ (*i.e.*, in the region $x \geq a$) there exists a magnetic field of strength B, directed along the positive y-axis. Find :



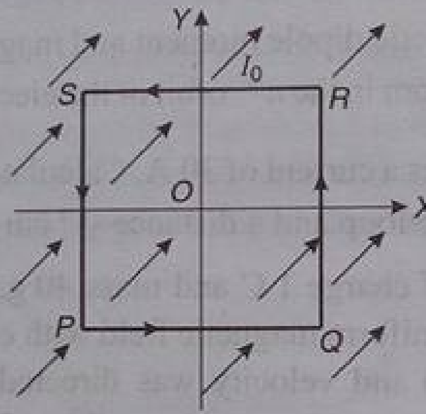
(a) At which point does the particle meets the line $x = a$

(b) The pitch of the helix formed after the particle enters the region $x \geq a$. Mass of the particle is m.

7. A charged particle having charge 10^{-6} C and mass of 10^{-10} kg is fired from the middle of the plate making an angle 30° with plane of the plate. Length of the plate is 0.17 m and it is separated by 0.1 m. Electric field $E = 10^{-3}$ N/C is present between the plates. Just outside the plates magnetic field is present. Find the velocity of projection of charged particle and magnitude of the magnetic field perpendicular to the plane of the figure, if it has to graze the plate at C and A parallel to the surface of the plate. (Neglect gravity)



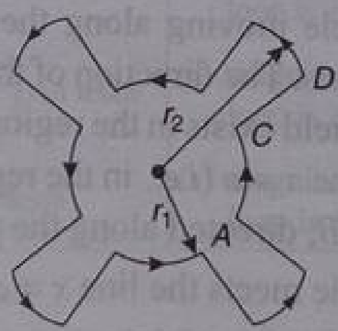
8. A uniform constant magnetic field B is directed at an angle of 45° to the x-axis in x-y plane. $PQRS$ is a rigid square wire frame carrying a steady current I_0, with its centre at the origin O. At time $t = 0$, the frame is at rest in the position shown in the figure with its sides parallel to x and y-axis. Each side of the frame has mass M and length L.



(a) What is the magnitude of torque $\vec{\tau}$ acting on the frame due to the magnetic field?

(b) Find the angle by which the frame rotates under the action of this torque in a short interval of time Δt, and the axis about which the rotation occurs (Δt, is so short that any variation in the torque during this interval may be neglected). Given : The moment of inertia of the frame about an axis through its centre perpendicular to its plane is $\frac{4}{3} ML^2$.

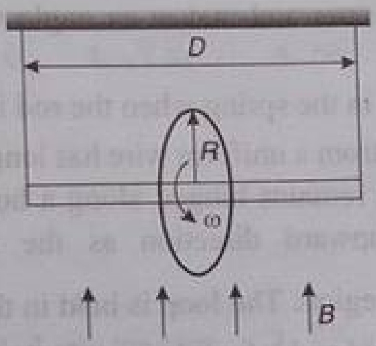
9. A current of 10 A flows around a closed path in a circuit which is in the horizontal plane as shown in the figure. The circuit consists of eight alternating arcs of radii $r_1 = 0.08$ m and $r_2 = 0.12$ m. Each subtends the same angle at the centre.



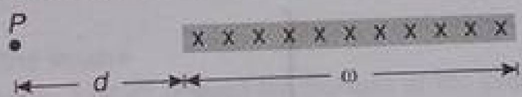
(a) Find the magnetic field produced by this circuit at the centre.

(b) An infinitely long straight wire carrying a current of 10 A is passing through the centre of the above circuit vertically with the direction of the current being into the plane of the circuit. What is the force acting on the wire at the centre due to the current in the circuit? What is the force acting on the arc AC and the straight segment CD due to the current at the centre?

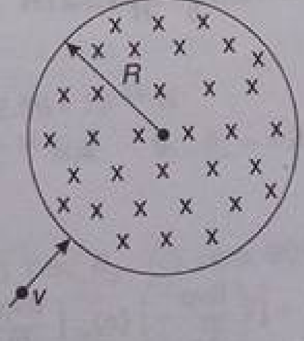
10. A ring of radius R having uniformly distributed charge Q is mounted on a rod suspended by two identical strings. The tension in strings in equilibrium is T_0. Now, a vertical magnetic field is switched on and ring is rotated at constant angular velocity ω. Find the maximum value of ω with which the ring can be rotated if the strings can withstand a maximum tension of $\frac{3T_0}{2}$.



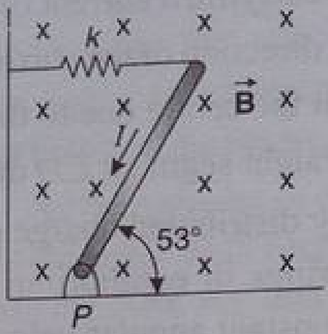
11. Figure shows a cross-section of a long ribbon of width ω that is carrying a uniformly distributed total current i into the page. Calculate the magnitude and direction of the magnetic field $\vec{\mathbf{B}}$ at a point P in the plane of the ribbon at a distance d from its edge.



12. A particle of mass m having a charge q enters into a circular region of radius R with velocity v directed towards the centre. The strength of magnetic field is B. Find the deviation in the path of the particle.



13. A thin, uniform rod with negligible mass and length 0.200 m is attached to the floor by a frictionless hinge at point P. A horizontal spring with force constant $k = 4.80$ N/m connects the other end of the rod with a vertical wall. The rod is in a uniform magnetic field $B = 0.340$ T directed into the plane of the figure. There is current $I = 6.50$ A in the rod, in the direction shown.



(a) Calculate the torque due to the magnetic force on the rod, for an axis at P. Is it correct to t
the total magnetic force to act at the centre of gravity of the rod when calculating the torq

(b) When the rod is in equilibrium and makes an angle of 53.0° with the floor, is the spr
stretched or compressed?

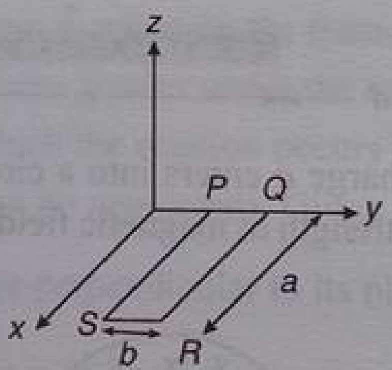
(c) How much energy is stored in the spring when the rod is in equilibrium?

14. A rectangular loop $PQRS$ made from a uniform wire has length a, width b and mass m. It is fre
rotate about the arm PQ, which remains hinged along a horizontal line taken as the y-axis
figure). Take the vertically upward direction as the z-axis. A uniform magnetic
$\vec{\mathbf{B}} = (3\hat{\mathbf{i}} + 4\hat{\mathbf{k}})B_0$ exists in the region. The loop is held in the x-y plane and a current I is pa
through it. The loop is now released and is found to stay in the horizontal position in equilibriun

(a) What is the direction of the current I in PQ?

(b) Find the magnetic force on the arm RS.

(c) Find the expression for I in terms of B_0, a, b and m.



ANSWERS

Introductory Exercise 23.1

1. $[LT^{-1}]$ 2. $(\vec{F}, \vec{v}), (\vec{F}, \vec{B})$ 3. No 4. $(-0.16\,\hat{i} - 0.32\,\hat{j} - 0.64\,\hat{k})$ N

Introductory Exercise 23.2

1. Yes, No 2. Along positive z-direction 3. (a) electron (b) electron 5. (a) π (b) π (c) $\frac{\pi}{6}$

6. 0.0167 cm, 0.7 cm 7. $r_d = \sqrt{2}\, r_p = \sqrt{2}\, r_\alpha$

Introductory Exercise 23.3

1. $v_0, \frac{mv_0}{qE_0}$ 2. $\left(\frac{2\pi m v_0 \sin\theta}{Bq}, 0, 0\right)$ 3. $\sqrt{2} B_0 i l$ 4. No

Introductory Exercise 23.4

1. $\frac{qR^2\omega}{4}$ 2. $(0.04\,\hat{j} - 0.07\,\hat{k})$ A-m^2

Introductory Exercise 23.5

1. (a) 28.3 μT into the page (b) 24.7 μT into the page 2. $\frac{\mu_0 i}{4\pi x}$ into the page

3. 58.0 μT into the page 4. 26.2 μT into the page 5. $\frac{\mu_0 i}{12}\left(\frac{1}{a} - \frac{1}{b}\right)$ out of the page 6. 13.0 μT

7. 9.98 N-m, clockwise as seen looking down from above.

Introductory Exercise 23.6

1. 20.0 μT toward the bottom of the square
2. 200 μT toward the top of the page, 133 μT toward the bottom of the page.
3. (a) $\frac{\mu_0 b r_1^2}{3}$ (b) $\frac{\mu_0 b R^3}{3 r_2}$

AIEEE Corner

Subjective Questions (Level 1)

1. Positive 2. 9.47×10^6 m/s 3. 2.56×10^{-14} N
4. (a) $(6.24 \times 10^{-14}\ \text{N})\hat{k}$ (b) $-(6.24 \times 10^{-14}\ \text{N})\hat{k}$ 5. $B_x = -2.0$ T

6. (a) $\vec{B} = (10^{-3}\ \text{T})\hat{i}$ (b) $F_2 = 10^{-2}$ N
7. (a) $B_x = (-0.175)$T, $B_z = (-0.256)$T (b) Yes, B_y (c) zero, 90°
8. (a) $-qvB\hat{k}$ (b) $+qvB\hat{j}$ (c) zero (d) $\frac{-qvB}{\sqrt{2}}\hat{j}$ (e) $\left(-\frac{qvB}{\sqrt{2}}\right)(\hat{j} + \hat{k})$

9. 8.38×10^{-4} T 10. (a) 8.35×10^6 m/s (b) 2.62×10^{-8} s (c) 7.26 kV
11. (a) $-q$ (b) $\frac{\pi m}{Bq}$ 12. (a) 1.6×10^{-4} T into the page (b) 1.11×10^{-7} s

13. $\vec{V} = V_x \hat{i} + V_y \cos\omega t\, \hat{j} - V_y \sin\omega t\, \hat{k}$, Here $\omega = \frac{Be}{m}$ 14. 4.73×10^{-3} T

15. (a) $\frac{mv_0}{2B_0q}$ (b) $-v_0\hat{i}, \frac{\pi m}{B_0 q}$ **16.** $\vec{E} = (-0.1\ V/m)\hat{k}$

17. $V_x = \frac{qB_0}{m}z, V_y = 0, V_z = \sqrt{\frac{2qE_0z}{m} - \left(\frac{qB_0}{m}\right)^2 z^2}$, $v = \sqrt{\frac{2qE_0z}{m}}$ **18.** $\frac{2\pi mE\tan\theta}{qB^2}$ **19.** 9.7 A

20. 0.47 A from left to right **21.** (a) 817.5 V (b) 112.8 m/s^2

22. (a) $(0.023\ N)\hat{k}$ (b) $(0.02\ N)\hat{j}$ (c) zero (d) $(-0.0098\ N)\hat{j}$ (e) $(-0.013\ N)\hat{j} + (-0.026\ N)\hat{k}$

23. $\vec{F}_{ab} = 0$, $\vec{F}_{bc} = (-0.04\ N)\hat{i}$, $\vec{F}_{cd} = (-0.04\ N)\hat{k}$, $\vec{F}_{da} = (0.04\hat{i} + 0.04\hat{k})\ N$

24. (a) $\vec{\tau} = (-9.6\hat{i} - 7.2\hat{j} + 8.0\hat{k}) \times 10^{-4}$ N-m (b) $U = -(6.0 \times 10^{-4})$ J **26.** $\frac{\pi R^3}{2\mu_0}$

27. (a) 76.7° (b) 76.7° **28.** –2.42 J

29. (a) 1.5×10^{-16} s (b) 1.1 mA (c) 9.3×10^{-24} A-m^2

30. $\vec{M} = 2Il^2\hat{j}$ **31.** zero **32.** 2.0 μT **33.** 2×10^{-6} T **34.** $y = \left(\frac{I_1}{I_2}\right)x$

35. $\frac{\mu_0 i}{4\sqrt{2}\pi a}$ (inwards) **36.** 2 rad **37.** (a) Between the wires, 30.0 cm from wire carrying 75.0 A
(b) 20.0 cm from wire carrying 25.0 A and 60.0 cm from wire carrying 75.0 A

38. 69 **39.** $I_1 = \left(\frac{\pi D}{R}\right)I_2$ **40.** (a) 2.77 A (b) 0.0184 m

41. 2.0 A toward bottom of page **42.** (a) $\frac{-\mu_0 qv_0 I}{4R}\hat{k}$ (b) $\vec{F}_1 = \vec{F}_2 = 2BIR\hat{i}, \vec{F} = 4BIR\hat{i}$

43. (a) $\frac{\mu_0 in^2 \sin\left(\frac{\pi}{n}\right)\tan\left(\frac{\pi}{n}\right)}{2\pi^2 r}$ (b) $\frac{\mu_0 i}{2r}$ **44.** (a) 0.3 A (b) -3.83×10^{-7} T-m

45. (a) zero (b) -5.0×10^{-6} T (c) 2.5×10^{-6} T-m (d) 5.0×10^{-6} T-m

46. (a) $\frac{\mu_0 I}{4r}\left(\frac{2r^2 - a^2}{4r^2 - a^2}\right)$ to the left (b) $\frac{\mu_0 I}{\pi r}\left(\frac{2r^2 + a^2}{4r^2 + a^2}\right)$ towards the top of the page

47. $B_P = 0, B_Q = \mu_0\lambda$

48. (a) $(-1.92 \times 10^{-5}\ T)\hat{k}$ (b) zero (c) $(1.92 \times 10^{-5}\ T)\hat{i}$ (d) $(6.79 \times 10^{-6}\ T)\hat{i}$

49. (a) zero (b) $(-1.31 \times 10^{-6}\ T)\hat{k}$ (c) $(-6.53 \times 10^{-7}\ T)\hat{k}$ (d) $(1.31 \times 10^{-6}\ T)\hat{j}$

50. 1.64×10^{-6} T, into the page **51.** 0.2 s **52.** (a) 8.33 A (b) opposite

53. 3×10^{-4} N **54.** $\frac{\mu_0 I_1 I_2 L}{2\pi a}$, zero

Objective Questions (Level 1)

1. (a)	2. (c)	3. (c)	4. (c)	5. (c)	6. (b)	7. (d)	8. (c)	9. (d)	10. (a)
11. (c)	12. (d)	13. (c)	14. (a)	15. (c)	16. (a)	17. (d)	18. (c)	19. (c)	20. (c)
21. (c)	22. (b)	23. (d)	24. (c)	25. (a)	26. (b)	27. (c)	28. (a)	29. (b)	30. (a)
31. (a)	32. (a)	33. (b)	34. (d)	35. (a)					

JEE Corner

Assertion and Reason

1. (c) 2. (c) 3. (b) 4. (d) 5. (c) 6. (b) 7. (a) 8. (c) 9. (a) 10. (d)
11. (d)

Objective Questions (Level 2)

1.(a) 2.(c) 3.(c) 4.(c) 5.(d) 6.(d) 7.(b) 8.(d) 9.(b) 10.(c)
11.(d) 12.(a) 13.(b) 14.(a) 15.(c) 16.(c) 17.(d) 18.(c) 19.(c) 20.(d)
21.(b) 22.(c) 23.(d) 24.(d) 25.(a) 26.(b) 27.(a)

More than One Correct Options

1.(a,c) 2.(a,c,d) 3.(a,b,d) 4.(b,c,d) 5.(b,d) 6.(a,b,c,d) 7.(a,b,c,d) 8.(a,c,d) 9.(a,c,d) 10.(a,b,c)

Match the Columns

1. (a) → r (b) → q (c) → p (d) → r
2. (a) → r (b) → s (c) → q (d) → p
3. (a) → p,s (b) → p,q (c) → p,r (d) → p,s
4. (a) → q (b) → r (c) → s (d) → s
5. (a) → q (b) → r (c) → q (d) → r
6. (a) → q,s (b) → p,r (c) → p,r (d) → q,s
7. (a) → r,s (b) → r,s (c) → q,r (d) → p,r

Subjective Questions (Level 2)

1. $\vec{F} = \frac{\mu_0 I^2}{\pi}\left[\frac{1}{2} - \frac{1}{\sqrt{3}} \ln\left(\frac{2+\sqrt{3}}{2}\right)\right](\hat{i})$ 2. $M = \frac{neh}{4\pi m}, B = \frac{\mu_0 \pi m^2 e^7}{8 \varepsilon_0^3 h^5 n^5}$ 3. 2.7×10^{-4} T

4. (0.2 m, 0.2 m, 0.2 m) 5. 2×10^{-5} N 6. (a) $y = \frac{Ea^2}{4V}$ (b) $p = \frac{\pi Ea}{B}\sqrt{\frac{2m}{qV}}$

7. 2.0 m/s, 3.46 mT 8. (a) $I_0 L^2 B$ (b) $\frac{3}{4}\frac{I_0 B}{M}(\Delta t)^2$

9. (a) 6.54×10^{-4} T (vertically upwards or outward normal to the paper)
(b) zero, zero, 8.1×10^{-6} N (inwards)

10. $\omega_{max} = \frac{DT_0}{BQR^2}$ 11. $B = \frac{\mu_0}{2\pi}\frac{i}{\omega} \ln\left(\frac{d+\omega}{d}\right)$ (upwards) 12. $2\tan^{-1}\left(\frac{BqR}{mv}\right)$

13. (a) 0.0442 N-m, clockwise, yes (b) stretched (c) 7.8×10^{-3} J

14. (a) P to Q (b) $IbB_0(3\hat{k} - 4\hat{i})$ (c) $\frac{mg}{6bB_0}$

24 Electromagnetic Induction

Chapter Contents

24.1 Introduction

Almost every modern device has electric circuits at its heart. We learned in the chapter of current electricity that an electromagnetic force (emf) is required for a current to flow in a circuit. But for most of the electric devices used in industry the source of emf is not a battery but an electrical generating station. In these stations other forms of energy are converted into electric energy. For example in a hydroelectric plant gravitational potential energy is converted into electric energy. Similarly, in a nuclear plant nuclear energy is converted into electric energy.

But how this conversion is done? Or what is the physics behind this? The branch of physics, known as **electromagnetic induction** gives the answer to all these queries. If the **magnetic flux** (ϕ_B) through a circuit changes, an emf and a current are induced in the circuit. Electromagnetic induction was discovered in 1830. The central principle of electromagnetic induction is **Faraday's law**. This law relates induced emf to change in magnetic flux in any loop, including a closed circuit. We will also discuss Lenz's law, which helps us to predict the directions of induced emf and current.

24.2 Magnetic Field Lines and Magnetic Flux

Let us first discuss the concept of magnetic field lines and magnetic flux. We can represent any magnetic field by **magnetic field lines**. Unlike the electric lines of force it is wrong to call them magnetic lines of force, because they do not point in the direction of the force on a charge. The force on a moving charged particle is always perpendicular to the magnetic field (or magnetic field lines) at the particle's position.

The idea of magnetic field lines is same as for the electric field lines as discussed in Chapter 21. The magnetic field at any point is tangential to the field line at that point. Where the field lines are close, the magnitude of field is large, where the field lines are far apart, the field magnitude is small. Also, because the direction of $\vec{B}$ at each point is unique, field lines never intersect. Unlike the electric field lines, magnetic lines form a closed loop.

Magnetic Flux

The flux associated with a magnetic field is defined in a similar manner to that used to define electric flux. Consider an element of area dS on an arbitrary shaped surface as shown in figure. If the magnetic field at this element is $\vec{B}$, the magnetic flux through the element is,

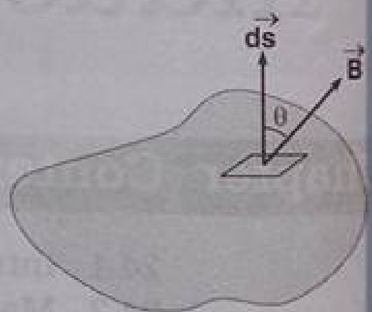


Fig. 24.1

$$d\phi_B = \vec{B} \cdot \vec{dS} = BdS\cos\theta$$

Here, $\vec{dS}$ is a vector that is perpendicular to the surface and has a magnitude equal to the area dS and θ is the angle between $\vec{B}$ and $\vec{dS}$ at that element. In general $d\phi_B$ varies from element to element. The total magnetic flux through the surface is the sum of the contributions from the individual area elements.

$$\therefore \quad \phi_B = \int BdS\cos\theta = \int \vec{B} \cdot \vec{dS}$$

Note down the following points regarding the magnetic flux :

(i) Magnetic flux is a scalar quantity (dot product of two vector quantities is a scalar quantity)

(ii) The SI unit of magnetic flux is tesla-meter^2 (1 T-m^2). This unit is called **weber** (1 Wb)

$$1\ \text{Wb} = 1\ \text{T-m}^2 = 1\ \text{N-m/A}$$

Thus, unit of magnetic field is also weber/m^2 (1 Wb/m^2),

or

$$1\ \text{T} = 1\ \text{Wb/m}^2$$

(iii) In the special case in which $\vec{\mathbf{B}}$ is uniform over a plane surface with total area S,

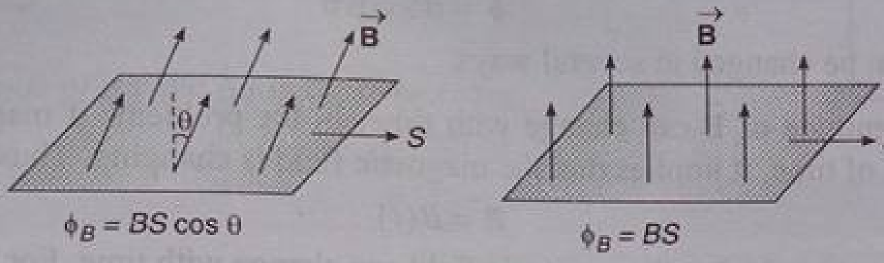


Fig. 24.2

$$\phi_B = BS\cos\theta$$

If $\vec{\mathbf{B}}$ is perpendicular to the surface, then $\cos\theta = 1$ and

$$\phi_B = BS$$

Gauss's Law for Magnetism

In Gauss's law the total electric flux through a closed surface is proportional to the total electric charge enclosed by the surface. For example if a closed surface encloses an electric dipole, the total electric flux is zero because the total charge is zero.

By analogy, if there were such as thing as a single magnetic charge (magnetic monopole), the total magnetic flux through a closed surface would be proportional to the total magnetic charge enclosed. But as no magnetic monopole has ever been observed, we conclude that **the total magnetic flux through a closed surface is zero.**

$$\oint \vec{\mathbf{B}} \cdot d\vec{\mathbf{S}} = 0$$

Unlike electric field lines that begin and end on electric charges, magnetic field lines never have end points. Such a point would otherwise indicate the existence of a monopole. For a closed surface the vector area element $d\vec{\mathbf{S}}$ always points out of the surface. However, for an open surface we choose one of the possible sides of the surface to be the positive and use that choice consistently.

24.3 Faraday's Law

This law states that, "the induced emf in a closed loop equals the negative of the time rate of change of magnetic flux through the loop."

$$e = -\frac{d\phi_B}{dt}$$

If a circuit is a coil consisting of N loops all of the same area and if ϕ_B is the flux through one loop, a emf is induced in every loop, thus the total induced emf in the coil is given by the expression,

$$e = -N\frac{d\phi_B}{dt}$$

The negative sign in the above equations is of important physical significance, which we will discuss in Art. 24.4.

Note down the following points regarding the Faraday's law:

(i) As we have seen, induced emf is produced only when there is a change in magnetic flux passing through a loop. The flux passing through the loop is given by,

$$\phi = BS\cos\theta$$

This, flux can be changed in several ways:

(a) The magnitude of $\vec{B}$ can change with time. In the problems if magnetic field is given a function of time, it implies that the magnetic field is changing. Thus,

$$B = B(t)$$

(b) The current producing the magnetic field can change with time. For this the current can be given as a function of time. Hence,

$$i = i(t)$$

(c) The area enclosed by the loop can change with time. This can be done by pulling a loop inside (or outside) a magnetic field. By doing so, the area enclosed by loop (hatched area) can be changed.

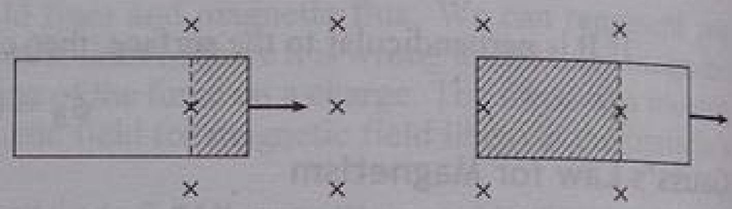


Fig. 24.3

(d) The angle θ between $\vec{B}$ and the normal to the loop can change with time. This can be done by rotating a loop in a magnetic field.

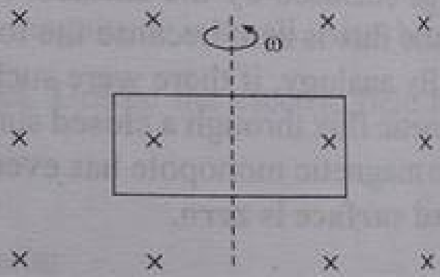


Fig. 24.4

(e) Any combination of the above can occur.

(ii) When the magnetic flux passing through a loop is changed an induced emf and hence, an induced current is produced in the circuit. If R is the resistance of the circuit, then induced current is given by,

$$i = \frac{e}{R} = \frac{1}{R}\left(\frac{-d\phi_B}{dt}\right)$$

Current starts flowing in the circuit, means flow of charge takes place. Charge flown in the circuit in time dt will be given by,

$$dq = i\,dt = \frac{1}{R}(-d\phi_B)$$

Thus, for a time interval Δt we can write,

$$e = -\frac{\Delta\phi_B}{\Delta t},\quad i = \frac{1}{R}\left(\frac{-\Delta\phi_B}{\Delta t}\right) \text{ and } \Delta q = \frac{1}{R}(-\Delta\phi_B)$$

From these equations we can see that e and i are inversely proportional to Δt while Δq is independent of Δt. It depends on magnitude of change in flux, not the time taken in it. To understand it let us take an example.

Sample Example 24.1 *A square loop ACDE of area 20 cm² and resistance 5 Ω is rotated in a magnetic field $\vec{B} = 2T$ through 180°*

(a) in 0.01 s and

(b) in 0.02 s

Find the magnitude of e, i and Δq in both the cases.

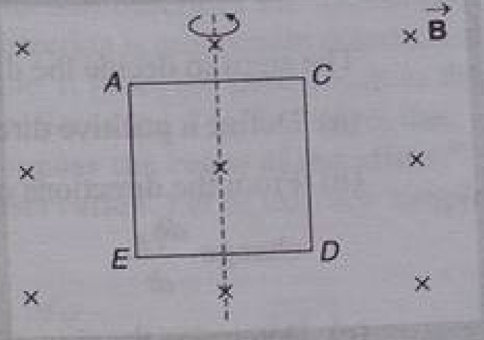


Fig. 24.5

Solution Let us take the area vector $\vec{S}$ perpendicular to plane of loop inwards. So initially, $\vec{S} \uparrow\uparrow \vec{B}$ and when it is rotated by 180°, $\vec{S} \uparrow\downarrow \vec{B}$. Hence, initial flux passing through the loop,

$$\phi_i = BS\cos 0° = (2)(20 \times 10^{-4})(1) = 4.0 \times 10^{-3} \text{ Wb}$$

Flux passing through the loop when it is rotated by 180°,

$$\phi_f = BS\cos 180° = (2)(20 \times 10^{-4})(-1) = -4.0 \times 10^{-3} \text{ Wb}$$

Therefore, change in flux,

$$\Delta\phi_B = \phi_f - \phi_i = -8.0 \times 10^{-3} \text{ Wb}$$

(a) Given $\Delta t = 0.01 \text{ s}$, $R = 5\,\Omega$

$$\therefore \quad |e| = \left| -\frac{\Delta\phi_B}{\Delta t} \right| = \frac{8.0 \times 10^{-3}}{0.01} = 0.8 \text{ V}$$

$$i = \frac{|e|}{R} = \frac{0.8}{5} = 0.16 \text{ A}$$

and

$$\Delta q = i\Delta t = 0.16 \times 0.01 = 1.6 \times 10^{-3} \text{ C}$$

(b) $\Delta t = 0.02 \text{ s}$

$$\therefore \quad |e| = \left| -\frac{\Delta\phi_B}{\Delta t} \right| = \frac{8.0 \times 10^{-3}}{0.02} = 0.4 \text{ V}$$

$$i = \frac{|e|}{R} = \frac{0.4}{5} = 0.08 \text{ A}$$

and

$$\Delta q = i\Delta t = (0.08)(0.02) = 1.6 \times 10^{-3} \text{ C}$$

Note *Time interval Δt in part (b) is two times the time interval in part (a), so e and i are half while Δq is same.*

Solved Examples

Level 1

Example 1 *A coil consists of 200 turns of wire having a total resistanc of 2.0 Ω. Each turn is a square of side 18 cm, and a uniform magnetic field directed perpendicular to the plane of the coil is turned on. If the field changes linearly from 0 to 0.5 T in 0.80 s, what is the magnitude of induced emf and current in the coil while the field is changing?*

Solution From the Faraday's law,

$$\text{Induced emf}\,|e| = \frac{Nd\phi}{dt} = (N.S)\frac{\Delta B}{\Delta t}$$

$$= \frac{(200)\,(18\times10^{-2})^2\,(0.5-0)}{0.8}$$

$$= 4.05\ \text{V}$$ **Ans.**

Induced current $$i = \frac{|e|}{R} = \frac{4.05}{2} \approx 2.0\ \text{A}$$ **Ans.**

Example 2 *The magnetic flux threading a metal ring varies with time t according to $\phi_B = 3\,(at^3 - bt^2)\,T\text{-}m^2$ with $a = 2.00\ s^{-3}$ and $b = 6.00\ s^{-2}$. The resistance of the ring is 3.0 Ω. Determine the maximum current induced in the ring during the interval from $t = 0$ to $t = 2.0$ s.*

Solution Given $$\phi_B = 3\,(at^3 - bt^2)$$

$$\therefore \quad |e| = \left|\frac{d\phi_B}{dt}\right| = 9at^2 - 6bt$$

∴ Induced current $$i = \frac{|e|}{R} = \frac{9at^2 - 6bt}{3} = 3at^2 - 2bt$$

For current to be maximum,

$$\frac{di}{dt} = 0$$

$$\therefore \quad 6at - 2b = 0 \quad \text{or} \quad t = \frac{b}{3a}$$

i.e., at $t = \frac{b}{3a}$, current is maximum. This maximum current is,

$$i_{\max} = 3a\left(\frac{b}{3a}\right)^2 - 2b\left(\frac{b}{3a}\right)$$

$$= \frac{b^2}{3a} - \frac{2b^2}{3a}$$

Magnitude of this maximum current will be

$$i_{max} = \frac{b^2}{3a}$$

Substituting the given values of a and b, we have

$$i_{max} = \frac{(6)^2}{3(2)} = 6.0\ \text{A}$$ **Ans.**

Example 3 *Figure shows the top view of a rod that can slide without friction. The resistor is 6.0 Ω and a 2.5 T magnetic field is directed perpendicularly downward into the paper. Let $l = 1.20$ m.*

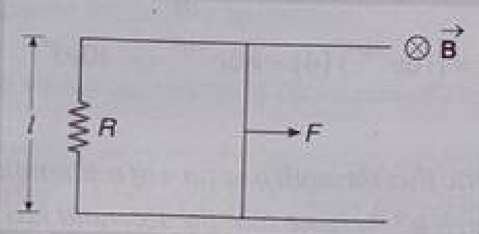


Fig. 24.65

(a) Calculate the force F required to move the rod to the right at a constant speed of 2.0 m/s.
(b) At what rate is energy delivered to the resistor.
(c) Show that this rate is equal to the rate of work done by the applied force.

Solution The motional emf in the rod, $e = Bvl$

or, $$e = (2.5)(2.0)(1.2)\ \text{V} = 6.0\ \text{V}$$

The current in the circuit $i = \frac{e}{R} = \frac{6.0}{6.0} = 1.0$ A

(a) The magnitude of force F required will be equal to the magnetic force acting on the rod, which opposes the motion.

∴ $$F = F_m = ilB$$

or, $$F = (1.0)(1.2)(2.5)\ \text{N} = 3\text{N}$$ **Ans.**

(b) Rate by which energy is delivered to the resistor is,

$$P_1 = i^2R = (1)^2(6.0) = 6\ \text{W}$$ **Ans.**

(c) The rate by which work is done by the applied force is,

$$P_2 = F \cdot v = (3)(2.0) = 6\ \text{W}$$

$$P_1 = P_2$$ **Hence proved.**

Example 4 *In the figure shown $i = 10e^{-4t}$ A. Find V_L and V_{ab}.*

Fig. 24.66

Solution

$$V_L = +L\frac{di}{dt}$$

$$= (2)\frac{d}{dt}(10e^{-4t})$$

$$= -80\,e^{-4t}$$

Further,

$$V_a - iR - L\frac{di}{dt} = V_b$$

$\therefore$

$$V_a - V_b = iR + L\frac{di}{dt}$$

or

$$V_{ab} = (10e^{-4t})(4) - 80e^{-4t} = -40e^{-4t}$$ **Ans.**

Example 5 *(a) What is the magnetic flux through one turn of a solenoid of self inductance* 8.0×10^{-5} *H when a current of* 3.0 *A flows through it? Assume that the solenoid has* 1000 *turns and is wound from wire of diameter* 1.0 *mm.*

(b) What is the cross-sectional area of the solenoid?

Solution Given, $L = 8.0\times10^{-5}$ H, $i = 3.0$ A and $N = 1000$

(a) From the relation, $L = \dfrac{N\phi}{i}$

The flux linked with one turn,

$$\phi = \frac{Li}{N} = \frac{(8.0\times10^{-5})(3.0)}{1000} = 2.4\times10^{-7}\text{ Wb}$$

(b) This $\phi = BS = (\mu_0 ni)(S)$

Here, n = number of turns per unit length

$$= \frac{N}{l} = \frac{N}{N.d} = \frac{1}{d}$$

$\therefore$

$$\phi = \frac{\mu_0 iS}{d}$$

or

$$S = \frac{\phi d}{\mu_0 i} = \frac{(2.4\times10^{-7})\ (1.0\times10^{-3})}{(4\pi\times10^{-7})\ (3.0)} = 6.37\times10^{-5}\text{ m}^2$$ **Ans.**

Example 6 *A* 10 *H inductor carries a current of* 20 *A. How much ice at* 0°C *could be melted by the energy stored in the magnetic field of the inductor? Latent heat of ice is* 22.6×10^3 *J/kg.*

Solution Energy stored is $\frac{1}{2}Li^2$. This energy is completely used in melting the ice. Hence,

$$\frac{1}{2}Li^2 = mL_f$$

Here, L_f = latent heat of fusion

Hence, mass of ice melted, $m = \dfrac{Li^2}{2L_f}$

Substituting the values we have,

$$m = \frac{(10)(20)^2}{2(2.26 \times 10^3)} = 0.88 \text{ kg} \qquad \textbf{Ans.}$$

Example 7 *Two solenoids A and B spaced close to each other and sharing the same cylindrical axis have 400 and 700 turns respectively. A current of 3.50 A in coil A produced an average flux of $300\,\mu T\text{-}m^2$ through each turn of A and a flux of $90.0\,\mu T\text{-}m^2$ through each turn of B.*

(a) Calculate the mutual inductance of the two solenoids.
(b) What is the self inductance of A?
(c) What emf is induced in B when the current in A increases at the rate of 0.5 A/s?

Solution

(a)
$$M = \frac{N_B \phi_B}{i_A} = \frac{(700)(90 \times 10^{-6})}{3.5} = 1.8 \times 10^{-2} \text{ H} \qquad \textbf{Ans.}$$

$$L_A = \frac{N_A \phi_A}{i_A} = \frac{(400)(300 \times 10^{-6})}{3.5} = 3.43 \times 10^{-2} \text{ H} \qquad \textbf{Ans.}$$

(c)
$$e_B = M\left(\frac{di_A}{dt}\right) = (1.8 \times 10^{-2})(0.5) = 9.0 \times 10^{-3} \text{ V} \qquad \textbf{Ans.}$$

Example 8 *A sensitive electronic device of resistance 175 Ω is to be connected to a source of emf by a switch. The device is designed to operate with a current of 36 mA, but to avoid damage to the device, the current can rise to no more than 4.9 mA in the first 58 μs after the switch is closed. To protect the device it is connected in series with an inductor.*

(a) What emf must the source have?
(b) What inductance is required?
(c) What is the time constant?

Solution (a) Given $R = 175\,\Omega$ and peak value current

$$i_0 = 36 \times 10^{-3} \text{ A}$$

∴ The applied voltage

$$V = i_0 R = (175)(36 \times 10^{-3}) \text{ volt} = 6.3 \text{ volt} \qquad \textbf{Ans.}$$

(b) From the relation,

$$i = i_0 (1 - e^{-t/\tau_L})$$

we have,

$$(4.9) = (36)[1 - e^{-t/\tau_L}]$$

or

$$e^{-t/\tau_L} = 1 - \frac{4.9}{36} = 0.864$$

∴

$$\frac{t}{\tau_L} = -\ln(0.864) = 0.146$$

or $$\frac{t}{L/R} = 0.146$$

$\therefore$ $$\frac{Rt}{L} = 0.146$$

or $$L = \frac{Rt}{0.146} = \frac{(175)(58 \times 10^{-6})}{0.146} = 7.0 \times 10^{-2} \text{ H}$$ **Ans.**

(c) Time constant of the circuit,

$$\tau_L = \frac{L}{R} = \frac{7.0 \times 10^{-2}}{175} = 4.0 \times 10^{-4}$$ **Ans.**

Example 9 *For the circuit shown in figure, $E = 50 V$, $R_1 = 10 \Omega$, $R_2 = 20 \Omega$, $R_3 = 30 \Omega$ and $L = 2.0$ mH. Find the current through R_1 and R_2.*

(a) Immediately after switch S is closed.
(b) A long time after S is closed.
(c) Immediately after S is reopened.
(d) A long time after S is reopened.

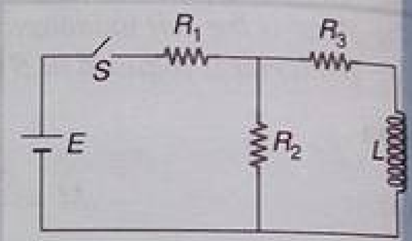


Fig. 24.67

Solution (a) Resistance offered by inductor immediately after switch is closed will be infinite. Therefore, current through R_3 will be zero and

$$\text{current through } R_1 = \text{current through } R_2 = \frac{E}{R_1 + R_2}$$

$$= \frac{50}{10 + 20} = \frac{5}{3} \text{ A}$$ **Ans.**

(b) After long time of closing the switch, resistance offered by inductor will be zero. In that case R_2 and R_3 are in parallel, and the resultant of these two is then in series with R_1. Hence,

$$R_{\text{net}} = R_1 + \frac{R_2 R_3}{R_2 + R_3} = 10 + \frac{(20)(30)}{20 + 30} = 22 \Omega$$

Current through the battery (or through R_1)

$$= \frac{E}{R_{\text{net}}} = \frac{50}{22} \text{ A}$$ **Ans.**

This current will distribute in R_2 and R_3 in inverse ratio of resistance. Hence,

$$\text{Current through } R_2 = \left(\frac{50}{22}\right)\left(\frac{R_3}{R_2 + R_3}\right)$$

$$= \left(\frac{50}{22}\right)\left(\frac{30}{30 + 20}\right) = \frac{15}{11} \text{ A}$$ **Ans.**

(c) Immediately after switch is reopened, the current through R_1 will become zero. But current through R_2 will be equal to the steady state current through R_3. Which is equal to,

$$\left(\frac{50}{22}-\frac{15}{11}\right)\text{A} = 0.91\text{ A}$$ **Ans.**

(d) A long after S is reopened, current through all resistors will be zero.

Example 10 *In an L-C circuit $L = 3.3$ H and $C = 840$ pF. At $t = 0$ charge on the capacitor is 105 μC and maximum. Compute the following quantities at $t = 2.0$ ms :*

(a) The energy stored in the capacitor.

(b) The energy stored in the inductor.

(c) The total energy in the circuit.

Solution Given, $L = 3.3$ H, $C = 840 \times 10^{-12}$ F

and $$q_0 = 105 \times 10^{-6} \text{ C}$$

The angular frequency of L-C oscillations is,

$$\omega = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{3.3 \times 840 \times 10^{-12}}} = 1.9 \times 10^4 \text{ rad/s}$$

Charge stored in the capacitor at time t, would be,

$$q = q_0 \cos \omega t$$

(a) At $$t = 2 \times 10^{-3} \text{ s}$$

$$q = (105 \times 10^{-6}) \cos [1.9 \times 10^4][2 \times 10^{-3}] = 100.3 \times 10^{-6} \text{ C}$$

∴ Energy stored in the capacitor

$$U_C = \frac{1}{2}\frac{q^2}{C}$$

$$= \frac{(100.3 \times 10^{-6})^2}{2 \times 840 \times 10^{-12}}$$

$$= 6.0 \text{ J}$$

(c) Total energy in the circuit

$$U = \frac{1}{2}\frac{q_0^2}{C} = \frac{(105 \times 10^{-6})^2}{2 \times 840 \times 10^{-12}}$$

$$= 6.56 \text{ J}$$

(b) Energy stored in inductor in the given time

= total energy in circuit – energy stored in capacitor

$= (6.56 - 6.0)$ J

$= 0.56$ J **Ans.**

Level 2

Example 1 *A conducting rod shown in figure of mass m and length l moves on two frictionless parallel rails in the presence of a uniform magnetic field directed into the page. The rod is given an initial velocity v_0 to the right and is released at $t = 0$. Find as a function of time,*

(a) the velocity of the rod

(b) the induced current and

(c) the magnitude of the induced emf.

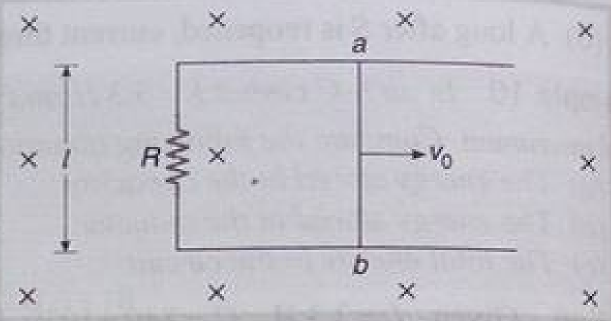


Fig. 24.68

HOW TO PROCEED *The initial velocity will produce an induced emf and hence, an induced current in the circuit. The current carrying wire will now experience a magnetic force ($\vec{F}_m$) in opposite direction of its velocity. The force will retard the motion of the conductor. Thus,*

Initial velocity → motional emf → induced current → magnetic force → retardation.

Solution (a) Let v be the velocity of the rod at time t.

Current in the circuit at this moment is,

$$i = \frac{Bvl}{R} \qquad \text{...(i)}$$

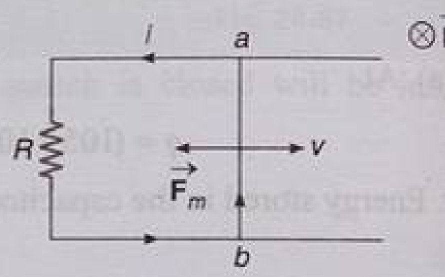


Fig. 24.69

From right hand rule we can see that this current is in counterclockwise direction.

The magnetic force is,

$$F_m = -ilB = -\frac{B^2l^2}{R}v$$

Here, negative sign denotes that the force is to the left and retards the motion. This is the only horizontal force acting on the bar, and hence, Newton's second law applied to motion in horizontal direction gives,

$$m\frac{dv}{dt} = F_m = -\frac{B^2l^2}{R}v$$

$$\therefore \qquad \frac{dv}{v} = -\left(\frac{B^2l^2}{mR}\right)dt$$

Integrating this equation using the initial condition that, $v = v_0$ at $t = 0$, we find that

$$\int_{v_0}^{v}\frac{dv}{v} = -\frac{B^2l^2}{mR}\int_0^t dt$$

Solving this equation, we find that

$$v = v_0e^{-t/\tau} \qquad \text{...(ii) Ans.}$$

where, $$\tau = \frac{mR}{B^2l^2}$$

This expression indicates that the velocity of the rod decreases exponentially with time under the action of the magnetic retarding force.

(b) $$i = \frac{Bvl}{R}$$

Substituting the value of v from Eq. (ii), we get

$$i = \frac{Blv_0}{R} e^{-t/\tau}$$ **Ans.**

(c) $$e = iR = Blv_0 e^{-t/\tau}$$ **Ans.**

i and e both decrease exponentially with time. v-t, i-t and e-t graphs are as shown in Fig. 24.70.

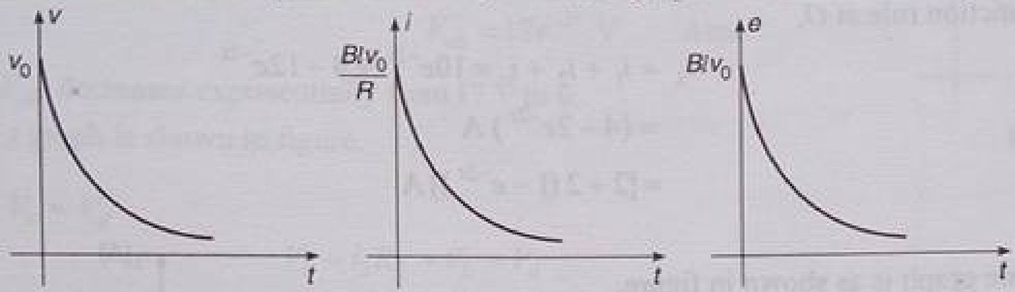


Fig. 24.70

Alternate solution : This problem can also be solved by energy conservation principle. Let at some instant velocity of the rod is v. As no external force is present. Energy is dissipated in the resistor at the cost of kinetic energy of the rod. Hence,

$$\left(-\frac{dK}{dt}\right) = \text{power dissipated in the resistor}$$

or $$-\frac{d}{dt}\left(\frac{1}{2}mv^2\right) = \frac{e^2}{R}$$

$$-mv\left(\frac{dv}{dt}\right) = \frac{B^2l^2v^2}{R} \quad \text{(as } e = Bvl\text{)}$$

∴ $$\frac{dv}{v} = -\frac{B^2l^2}{mR}\,dt$$

∴ $$\int_{v_0}^{v} \frac{dv}{v} = -\frac{B^2l^2}{mR}\int_0^t dt$$

or $$v = v_0 e^{-t/\tau} \quad \text{where } \tau = \frac{mR}{B^2l^2}$$

Example 2 *In the figure shown,* $i_1 = 10e^{-2t}$ *A,* $i_2 = 4$ *A and* $V_C = 3e^{-2t}$ *V. Determine:*

(a) i_L *and* V_L

(b) V_{ac}, V_{ab} *and* V_{cd}.

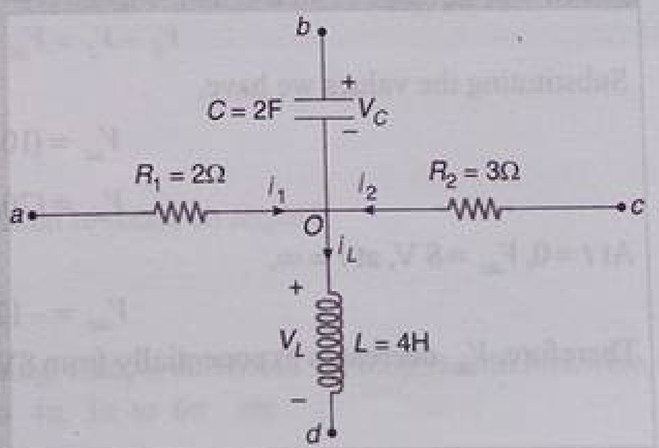
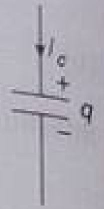


Fig. 24.71

Solution (a) Charge stored in the capacitor at time t,



$$q = CV_C$$
$$= (2)(3e^{-2t})$$
$$= 6e^{-2t}\ \text{C}$$

$$\therefore \quad i_c = \frac{dq}{dt} = -12e^{-2t}\ \text{A}$$ (direction of current is from b to O)

Applying junction rule at O,

$$i_L = i_1 + i_2 + i_c = 10e^{-2t} + 4 - 12e^{-2t}$$
$$= (4 - 2e^{-2t})\ \text{A}$$
$$= [2 + 2(1 - e^{-2t})]\ \text{A}$$ **Ans.**

i_L *versus* time graph is as shown in figure.

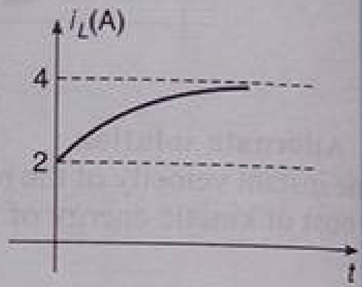


Fig. 24.72

i_L increases from 2 A to 4 A exponentially.

$$V_L = V_{od} = L\frac{di_L}{dt}$$
$$= (4)\frac{d}{dt}(4 - 2e^{-2t})$$
$$= 16e^{-2t}\ \text{V}$$ **Ans.**

V_L *versus* time graph is as shown in figure.
V_L decreases exponentially from 16 V to 0.

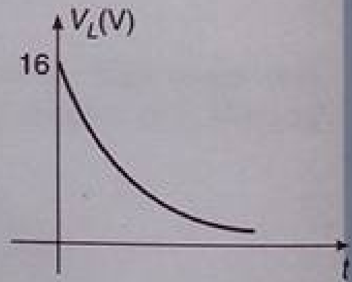


Fig. 24.73

(b) $V_{ac} = V_a - V_c$

$$V_a - i_1R_1 + i_2R_2 = V_c$$
$$\therefore \quad V_a - V_c = V_{ac} = i_1R_1 - i_2R_2$$

Substituting the values we have,

$$V_{ac} = (10e^{-2t})(2) - (4)(3)$$
$$V_{ac} = (20e^{-2t} - 12)\ \text{V}$$

At $t = 0$, $V_{ac} = 8$ V, at $t = \infty$,

$$V_{ac} = -12\text{V}$$

Therefore, V_{ac} decreases exponentially from 8V to –12V.

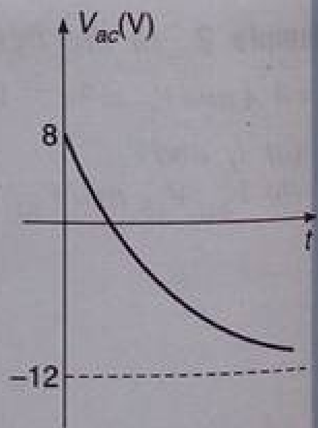


Fig. 24.74

$$V_{ab} = V_a - V_b$$

$$V_a - i_1R_1 + V_C = V_b$$

$\therefore$
$$V_a - V_b = V_{ab} = i_1R_1 - V_C$$

Substituting the values we have,

$$V_{ab} = (10e^{-2t})(2) - 3e^{-2t}$$

or
$$V_{ab} = 17e^{-2t}\text{ V} \qquad \textbf{Ans.}$$

Thus, V_{ab} decreases exponentially from 17 V to 0.

V_{ab} *versus* t graph is shown in figure.

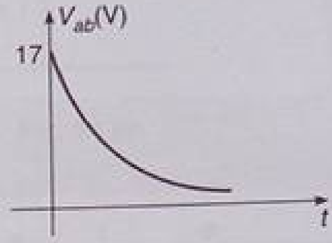


Fig. 24.75

$$V_{cd} = V_c - V_d$$

$$V_c - i_2R_2 - V_L = V_d$$

$\therefore$
$$V_c - V_d = V_{cd} = i_2R_2 + V_L$$

Substituting the values we have,

$$V_{cd} = (4)(3) + 16e^{-2t}$$

or
$$V_{cd} = (12 + 16e^{-2t})\text{ V} \quad \textbf{Ans.}$$

At $t = 0, V_{cd} = 28$ V and at $t = \infty, V_{cd} = 12$ V

i.e., V_{cd} decreases exponentially from 28 V to 12 V.

V_{cd} *versus* t graph is shown in figure.

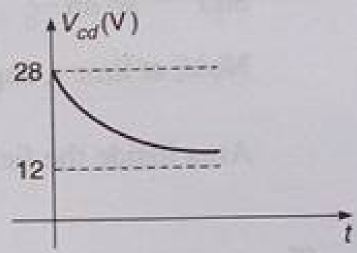


Fig. 24.76

Example 3 *A wire loop enclosing a semicircle of radius R is located on the boundary of a uniform magnetic field B. At the moment t = 0, the loop is set into rotation with a constant angular acceleration α about an axis O coinciding with a line of vector* $\vec{\mathbf{B}}$ *on the boundary. Find the emf induced in the loop as a function of time. Draw the approximate plot of this function. The arrow in the figure shows the emf direction taken to be positive.*

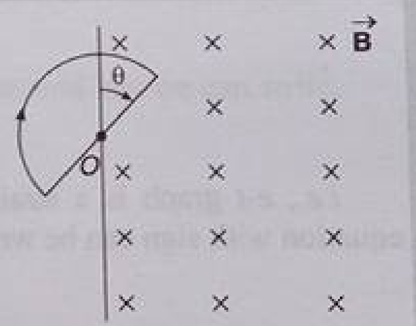


Fig. 24.77

Solution
$$\theta = \frac{1}{2}\alpha t^2$$

$\therefore$
$$t = \sqrt{\frac{2\alpha}{\theta}} = \text{time taken to rotate an angle } \theta$$

vhen $\theta = 0$ to π, 2π to 3π, 4π to 5π etc.

⊗ magnetic field passing through the loop is increasing. Hence, current in the loop is anticlockwise, or nduced emf is negative. And for, $\theta = \pi$ to 2π, 3π to 4π, 5π to 6π etc.

⊗ magnetic field passing through the loop is decreasing. Hence, current in the loop is clockwise, or emf is positive.

So, let

$$t_1 = \text{time taken to rotate angle} \quad \pi = \sqrt{\frac{2\pi}{\alpha}}$$

$$t_2 = \text{time taken to rotate angle} \quad 2\pi = \sqrt{\frac{4\pi}{\alpha}}$$

… … … … … …

$$t_n = \text{time taken to rotate angle} \quad n\pi = \sqrt{\frac{2n\pi}{\alpha}}$$

Now, 0 to t_1 emf is negative
t_1 to t_2 emf is positive
t_2 to t_3 emf is again negative
and so on.

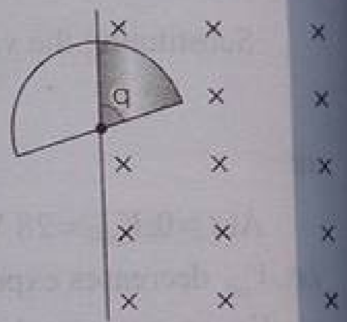


Fig. 24.78

Now, at time t, angle rotated is, $\theta = \frac{1}{2}\alpha t^2$

Area inside the field is, $S = (\pi R^2)\left(\frac{\theta}{2\pi}\right) = \frac{1}{2}R^2\theta$

or $S = \frac{1}{4}R^2\alpha t^2$

So, flux passing through the loop, $\phi = BS = \frac{1}{4}BR^2\alpha t^2$

$$e = \left|\frac{d\phi}{dt}\right| = \frac{1}{2}BR^2\alpha t$$

$$e \propto t$$

i.e., *e-t* graph is a straight line passing through origin. *e-t* equation with sign can be written as,

$$e = (-1)^n\left(\frac{1}{2}BR^2\alpha t\right) \qquad \textbf{Ans.}$$

Here, $n = 1, 2, 3 \ldots$ is the number of half revolutions that the loop performs at the given moment t.

The *e-t* graph is as shown in figure.

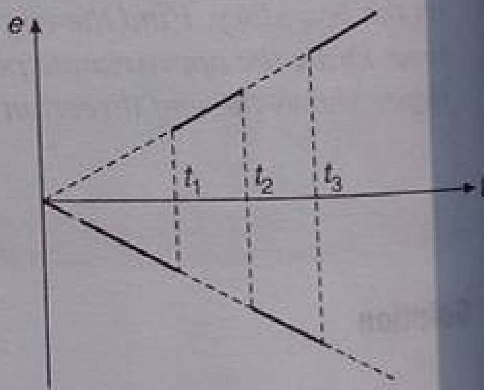


Fig. 24.79

Example 4 *A loop is formed by two parallel conductors connected by a solenoid with inductance L and a conducting rod of mass m which can freely (without friction) slide over the conductors. The conductors are located in a horizontal plane in a uniform vertical magnetic field B. The distance between the conductors is l. At the moment t = 0, the rod is imparted an initial velocity v_0 directed to the right. Find the law of its motion x (t) if the electric resistance of the loop is negligible.*

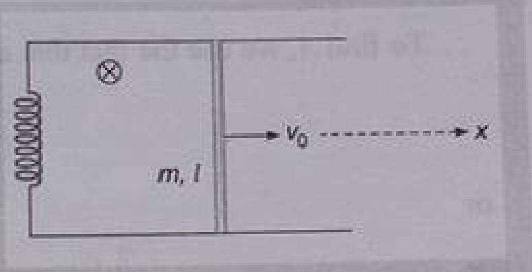


Fig. 24.80

SOLUTION Let at any instant of time, velocity of the rod is v towards right. The current in the circuit is i. In the figure,

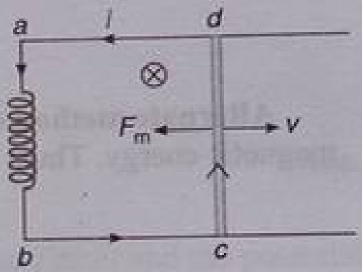


Fig. 24.81

$$V_a - V_b = V_d - V_c$$

or $$L\frac{di}{dt} = Bvl = Bl\frac{dx}{dt} \quad \left(\text{as } v = \frac{dx}{dt}\right)$$

i.e., $$Ldi = Bldx$$

Integrating, we get

$$Li = Blx$$

or $$i = \frac{Bl}{L}x \qquad \text{...(i)}$$

Magnetic force on the rod at this instant is,

$$F_m = ilB = \frac{B^2l^2}{L}x \qquad \text{...(ii)}$$

Since, this force is in opposite direction of $\vec{v}$, so from Newton's second law we can write,

$$m\left(\frac{d^2x}{dt^2}\right) = -\frac{B^2l^2}{L}x$$

or $$\left(\frac{d^2x}{dt^2}\right) = -\frac{B^2l^2}{mL}x$$

Comparing this with equation of SHM, *i.e.,*

$$\frac{d^2x}{dt^2} = -\omega^2 x$$

we have, $$\omega = \frac{Bl}{\sqrt{mL}}$$

Therefore, the rod will oscillate simple harmonically with angular frequency $\omega = Bl/\sqrt{mL}$. At time $t = 0$, rod was at $x = 0$ and it was moving towards positive x-axis. Hence, x-t equation of the rod is,

$$x = A\sin\omega t \qquad \text{...(iii)}$$

To find A, we use the fact that at $t=0$, v or $\frac{dx}{dt}$ has a value v_0. Hence,

$$\frac{dx}{dt} = v = A\omega\cos\omega t$$

or $$A\omega = v_0 \qquad (\text{at } t=0)$$

or $$A = \frac{v_0}{\omega}$$

Substituting in Eq. (iii), we have

$$x = \frac{v_0}{\omega}\sin\omega t, \text{ where } \omega = \frac{Bl}{\sqrt{mL}} \qquad \textbf{Ans.}$$

Alternate method of finding A : At $x = A$, $v = 0$, *i.e.*, whole of its kinetic energy is converted into magnetic energy. Thus,

$$\frac{1}{2}Li^2 = \frac{1}{2}mv_0^2$$

Substituting value of i from Eq. (i), with $x = A$, we have

$$L\left(\frac{Bl}{L}A\right)^2 = mv_0^2$$

or $$A = \frac{\sqrt{mL}}{Bl}v_0 = \frac{v_0}{\omega}$$

as $$\omega = \frac{Bl}{\sqrt{mL}} \qquad \textbf{Ans.}$$

Example 5 *A uniform wire of resistance per unit length λ is bent into a semicircle of radius a. The wire rotates with angular velocity ω in a vertical plane about a horizontal axis passing through C. A uniform magnetic field B exists in space in a direction perpendicular to paper inwards.*

(a) Calculate potential difference between points A and D. Which point is at higher potential?

(b) If points A and D are connected by a conducting wire of zero resistance find the potential difference between A and C.

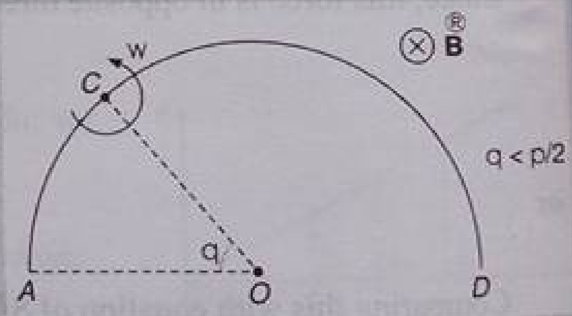


Fig. 24.82

Solution (a) Length of straight wire AC, is $l_1 = 2a\sin\left(\frac{\theta}{2}\right)$

Therefore, the motional emf (or potential difference) between points C and A is,

$$V_{CA} = V_C - V_A = \frac{1}{2}B\omega l_1^2 = 2a^2B\omega\sin^2\left(\frac{\theta}{2}\right) \qquad \ldots\text{(i)}$$

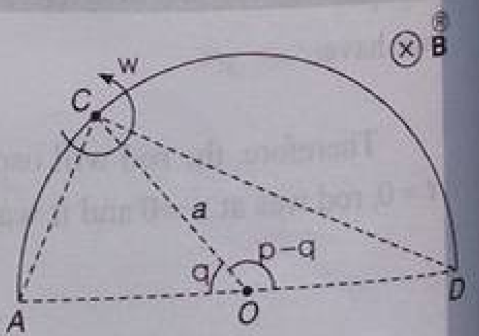


Fig. 24.83

From right hand rule we can see that $V_C > V_A$

Similarly, length of straight wire CD is,

$$l_2 = 2a\sin\left(\frac{\pi}{2} - \frac{\theta}{2}\right) = 2a\cos\left(\frac{\theta}{2}\right)$$

Therefore, the P.D. between points C and D is,

$$V_{CD} = V_C - V_D = \frac{1}{2}B\omega l_2^2 = 2a^2B\omega\cos^2\left(\frac{\theta}{2}\right) \quad \text{...(ii)}$$

with $V_C > V_D$

Eqs. (ii) – (i) gives,

$$V_A - V_D = 2a^2B\omega\left(\cos^2\frac{\theta}{2} - \sin^2\frac{\theta}{2}\right)$$

$$= 2a^2B\omega\cos\theta \qquad \textbf{Ans.}$$

A is at higher potential.

(b) When A and D are connected from a wire current starts flowing in the circuit and the potential difference between C and A has now a different value from $2a^2B\omega\sin^2\left(\frac{\theta}{2}\right)$.

Resistance between A and C is, $r_1 = (\text{length of arc } AC)\ \lambda = a\theta\lambda$

and between C and D is, $r_2 = (\text{length of arc } CD)\ \lambda = (\pi - \theta)\ a\lambda$

Now, the equivalent circuit can be drawn as shown in figure

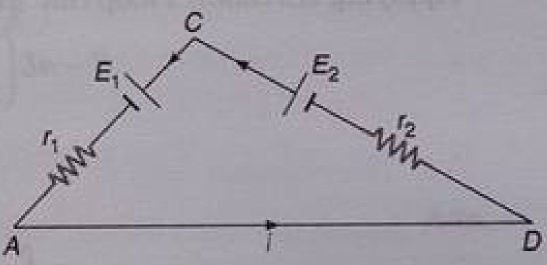


Fig. 24.84

In the figure, $E_1 = 2a^2B\omega\sin^2\left(\frac{\theta}{2}\right)$

and $E_2 = 2a^2B\omega\cos^2\left(\frac{\theta}{2}\right)$

with $E_2 > E_1$

$\therefore$ Current in the circuit is,

$$i = \frac{E_2 - E_1}{r_1 + r_2} = \frac{2a^2B\omega\cos\theta}{\pi a\lambda} = \frac{2aB\omega\cos\theta}{\pi\lambda}$$

and potential difference between points C and A is,

$$V'_{CA} = E_1 + ir_1 = 2a^2B\omega\sin^2\left(\frac{\theta}{2}\right) + \left(\frac{2aB\omega\cos\theta}{\pi\lambda}\right)(a\theta\lambda)$$

$$= 2a^2B\omega\left(\sin^2\frac{\theta}{2} + \frac{\theta}{\pi}\cos\theta\right) \qquad \textbf{Ans.}$$

Note *$V_{CA} = E_1$ when no current flows through the circuit and $V'_{CA} = E_1 + ir_1$ when a current i flows in the circuit.*

Example 6 *A battery of emf E and of negligible internal resistance is connected in an L-R circuit as shown in figure. The inductor has a piece of soft iron inside it. When steady state is reached the piece of soft iron is abruptly pulled out suddenly so that the inductance of the inductor decreases to nL with n< 1 with battery remaining connected. Calculate:*

(a) current as a function of time assuming t = 0 at the instant when piece is pulled.
(b) the work done to pull out the piece.
(c) thermal power generated in the circuit as a function of time.
(d) power supplied by the battery as a function of time.

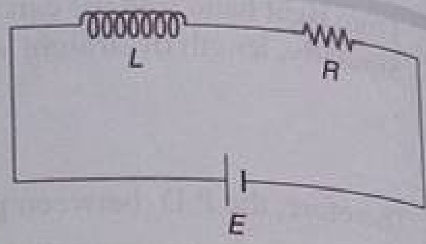


Fig. 24.85

HOW TO PROCEED *When the inductance of an inductor is abruptly changed, the flux passing through it remains constant.*

$$\phi = constant$$

$$\therefore \quad Li = constant \qquad \left(L = \frac{\phi}{i}\right)$$

Solution (a) At time $t = 0$, steady state current in the circuit is $i_0 = E/R$. Suddenly L reduces to nL $(n < 1)$, so current in the circuit at time $t = 0$ will increase to $\frac{i_0}{n} = \frac{E}{nR}$. Let i be the current at time t.

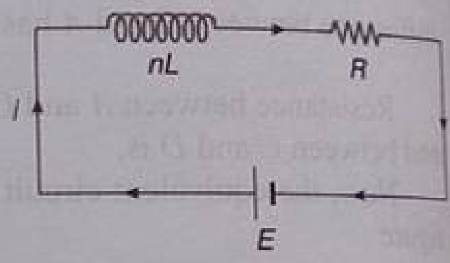


Fig. 24.86

Applying Kirchhoff's loop rule we have,

$$E - nL\left(\frac{di}{dt}\right) - iR = 0$$

$$\therefore \quad \frac{di}{E - iR} = \frac{1}{nL}\,dt$$

$$\therefore \quad \int_{i_0/n}^{i} \frac{di}{E - iR} = \frac{1}{nL}\int_0^t dt$$

Solving this equation, we get $$i = i_0 - \left(i_0 - \frac{i_0}{n}\right)e^{-t/\tau_L}$$ **Ans.**

Here, $$i_0 = \frac{E}{R} \quad \text{and} \quad \tau_L = \frac{nL}{R}$$

From the i-t equation, we get $i = \frac{i_0}{n}$ at $t = 0$ and $i = i_0$ at $t = \infty$

The i-t graph is as shown in figure.

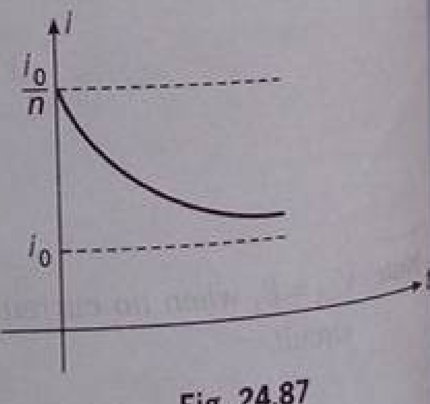


Fig. 24.87

Note *At $t = 0$, current in the circuit is $\frac{i_0}{n}$. Current in the circuit in steady state will be again i_0. So, it will decrease exponentially from $\frac{i_0}{n}$ to i_0. From the i-t graph the equation can be formed without doing any calculation.*

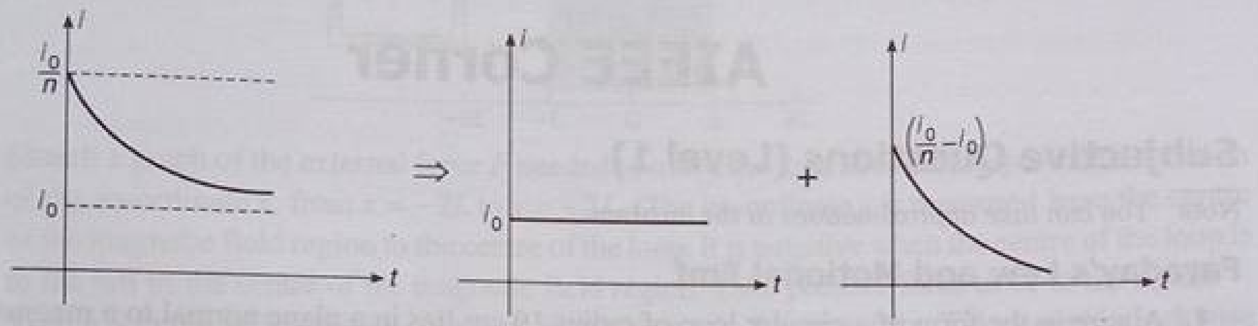


Fig. 24.88

$$\therefore \quad i = i_0 + \left(\frac{i_0}{n} - i_0\right) e^{-t/\tau_L}$$

(b) Work done to pull out the piece,

$$W = U_f - U_i = \frac{1}{2} L_f i_f^2 - \frac{1}{2} L_i i_i^2$$

$$= \frac{1}{2}(nL)\left(\frac{E}{nR}\right)^2 - \frac{1}{2}(L)\left(\frac{E}{R}\right)^2$$

$$= \frac{1}{2} L \left(\frac{E}{R}\right)^2 \left(\frac{1}{n} - 1\right)$$

$$= \frac{1}{2} L \left(\frac{E}{R}\right)^2 \left(\frac{1-n}{n}\right) \quad \textbf{Ans.}$$

(c) Thermal power generated in the circuit as a function of time is,

$$P_1 = i^2 R \quad \textbf{Ans.}$$

Here, i the current calculated in part (a).

(d) Power supplied by the battery as a function of time is,

$$P_2 = Ei \quad \textbf{Ans.}$$

EXERCISES

AIEEE Corner

Subjective Questions (Level 1)

Note *You can take approximations in the answers.*

Faraday's Law and Motional Emf

1. A wire in the form of a circular loop of radius 10 cm lies in a plane normal to a magnetic field of 100 T. If this wire is pulled to take a square shape in the same plane in 0.1 s, find the average induced emf in the loop.

2. A closed coil consists of 500 turns has area $4\ \text{cm}^2$ and a resistance of $50\ \Omega$. The coil is kept with its plane perpendicular to a uniform magnetic field of $0.2\ \text{Wb/m}^2$. Calculate the amount of charge flowing through the coil if it is rotated through $180°$.

3. A small coil is introduced between the poles of an electromagnet so that its axis coincides with the magnetic field direction. The cross-sectional area of the coil is equal to $S = 3.0\ \text{mm}^2$, the number of turns is $N = 60$. When the coil turns through $180°$ about its diameter, a galvanometer connected to the coil indicates a charge $q = 4.5\ \mu\text{C}$ flowing through it. Find the magnetic induction magnitude between the poles, provided the total resistance of the electric circuit equals $R = 40\ \Omega$.

4. The magnetic field in a certain region is given by $\vec{\mathbf{B}} = (4.0\,\hat{\mathbf{i}} - 1.8\,\hat{\mathbf{k}}) \times 10^{-3}$ T. How much flux passes through a $5.0\ \text{cm}^2$ area loop in this region if the loop lies flat on the x-y plane?

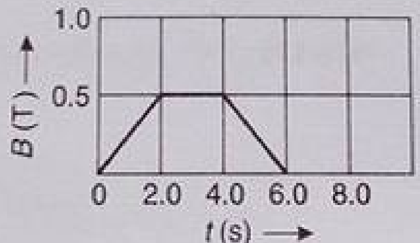
5. A horizontal wire 0.8 m long is falling at a speed of 5 m/s perpendicular to a uniform magnetic field of 1.1 T, which is directed from east to west. Calculate the magnitude of the induced emf. Is the north or south end of the wire positive?

6. The magnetic field through a single loop of wire, 12 cm in radius and of $8.5\ \Omega$ resistance, changes with time as shown in figure. Calculate the emf in the loop as a function of time. Consider the time intervals

   (a) $t = 0$ to $t = 2.0$ s,

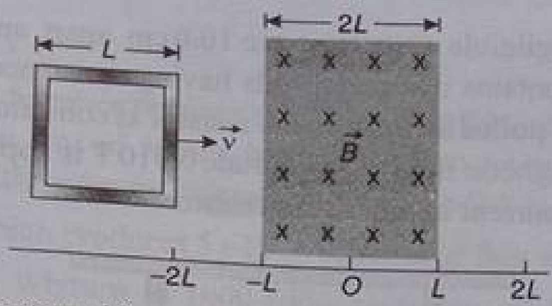
   (b) $t = 2.0$ s to $t = 4.0$ s,

   (c) $t = 4.0$ s to $t = 6.0$ s.



   The magnetic field is perpendicular to the plane of the loop.

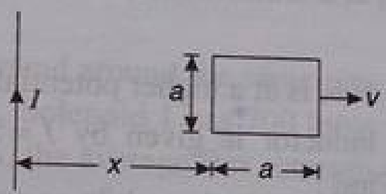
7. A square loop of wire with resistance R is moved at constant speed v across a uniform magnetic field confined to a square region whose sides are twice the lengths of those of the square loop.



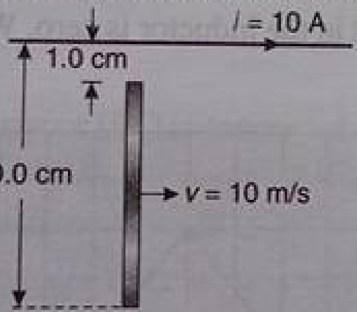
(a) Sketch a graph of the external force F needed to move the loop at constant speed, as a function of the co-ordinate x, from $x = -2L$ to $x = +2L$. (The co-ordinate x is measured from the centre of the magnetic field region to the centre of the loop. It is negative when the centre of the loop is to the left of the centre of the magnetic field region. Take positive force to be to the right).

(b) Sketch a graph of the induced current in the loop as a function of x. Take counterclockwise currents to be positive.

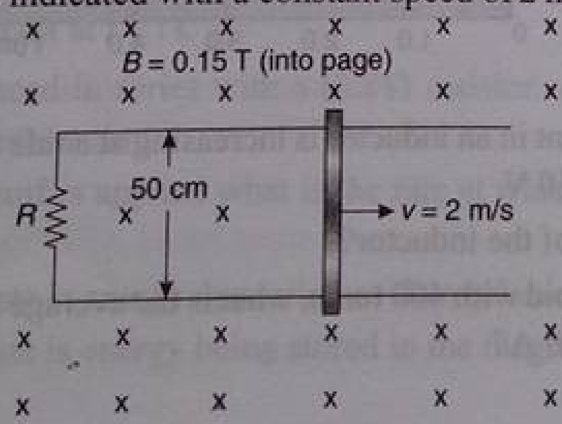
8. A square frame with side a and a long straight wire carrying a current i are located in the same plane as shown in figure. The frame translates to the right with a constant velocity v. Find the emf induced in the frame as a function of distance x.



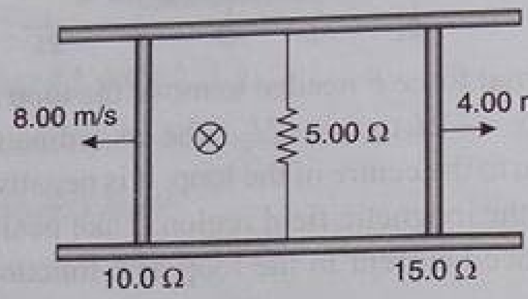
9. In figure a wire perpendicular to a long straight wire is moving parallel to the later with a speed $v = 10\,\text{m/s}$ in the direction of the current flowing in the later. The current is 10 A. What is the magnitude of the potential difference between the ends of the moving wire?



. As shown in figure, a metal rod completes the circuit. The circuit area is perpendicular to a magnetic field with $B = 0.15\,\text{T}$. If the resistance of the total circuit is $3\,\Omega$, how large a force is needed to move the rod as indicated with a constant speed of $2\,\text{m/s}$?

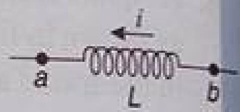


11. Two parallel rails with negligible resistance are 10.0 cm apart and are connected by a 5.00 Ω resistor. The circuit also contains two metal rods having resistance of 10.0 Ω and 15.0 Ω sliding along the rails. The rods are pulled away from the resistor at constant speeds 8.00 m/s and 4.00 m/s respectively. A uniform magnetic field of magnitude 0.010 T is applied perpendicular to the plane of the rails. Determine the current in the 5.00 Ω resistor.



Self Inductance

12. The inductor shown in figure has inductance 0.54 H and carries a current in the direction shown that is decreasing at a uniform rate, $di/dt = -0.030$ A/s:



(a) Find the self-induced emf.

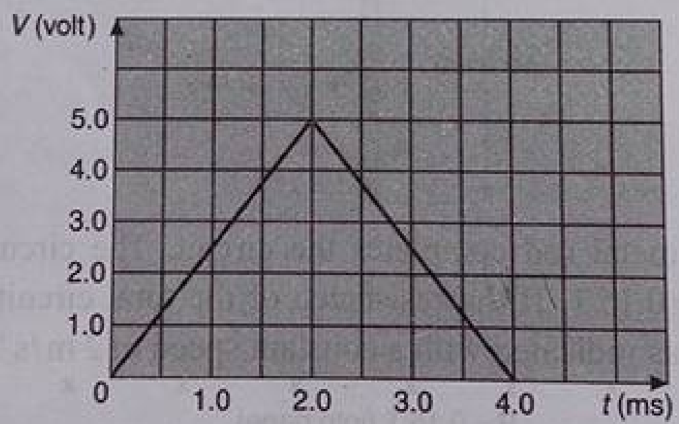
(b) Which end of the inductor, a or b, is at a higher potential?

13. The current (in Ampere) in an inductor is given by $I = 5 + 16t$, where t is in seconds. The self-induced emf in it is 10 mV. Find :

(a) the self-inductance, and

(b) the energy stored in the inductor and the power supplied to it at $t = 1$ s

14. The potential difference across a 150 mH inductor as a function of time is shown in figure. Assume that the initial value of the current in the inductor is zero. What is the current when $t = 2.0$ ms? and $t = 4.0$ ms?



15. At the instant when the current in an inductor is increasing at a rate of 0.0640 A/s, the magnitude of the self-induced emf is 0.0160 V.

(a) What is the inductance of the inductor?

(b) If the inductor is a solenoid with 400 turns, what is the average magnetic flux through each turn when the current is 0.720 A?

Mutual Inductance

16. Calculate the mutual inductance between two coils when a current of 4 A changes to 12 A in 0.5 s in primary and induces an emf of 50 mV in the secondary. Also calculate the induced emf in the secondary if current in the primary changes from 3 A to 9 A is 0.02 s.

17. A coil has 600 turns which produces 5×10^{-3} Wb/turn of flux when 3 A current flows in the wire. This produced 6×10^{-3} Wb/turn in 1000 turns secondary coil. When the switch is opened the current drops to zero in 0.2 s in primary. Find :

(a) mutual inductance

(b) the induced emf in the secondary

(c) the self inductance of the primary coil.

18. Two coils have mutual inductance $M = 3.25 \times 10^{-4}$ H. The current i_1 in the first coil increases at a uniform rate of 830 A/s.

(a) What is the magnitude of the induced emf in the second coil? Is it constant?

(b) Suppose that the current described is in the second coil rather than the first. What is the induced emf in the first coil?

19. Two toroidal solenoids are wound around the same pipe so that the magnetic field of one passes through the turns of the other. Solenoid 1 has 700 turns and solenoid 2 has 400 turns. When the current in solenoid 1 is 6.52 A, the average flux through each turn of solenoid 2 is 0.0320 Wb.

(a) What is the mutual inductance of the pair of solenoids?

(b) When the current in solenoid 2 is 2.54 A, what is the average flux through each turn of solenoid 1?

L–R Circuits

20. Show that L/R has units of time.

21. A coil of inductance 1 H and resistance 10 Ω is connected to a resistanceless battery of emf 50 V at time $t = 0$. Calculate the ratio of the rate at which magnetic energy is stored in the coil to the rate at which energy is supplied by the battery at $t = 0.1$ s.

22. A coil of inductance 2 H and resistance 10 Ω are in a series circuit with an open key and a cell of constant 100 V with negligible resistance. At time $t = 0$, the key is closed. Find :

(a) the time constant of the circuit.

(b) the maximum steady current in the circuit.

(c) the current in the circuit at $t = 1$ s.

23. A 3.56 H inductor is placed in series with a 12.8 Ω resistor. An emf of 3.24 V is then suddenly applied across the *RL* combination.

(a) At 0.278 s after the emf is applied what is the rate at which energy is being delivered by the battery?

(b) At 0.278 s, at what rate is energy appearing as thermal energy in the resistor?

(c) At 0.278 s, at what rate is energy being stored in the magnetic field?

24. An inductor with an inductance of 2.50 H and a resistance of 8.00 Ω is connected to the terminals of a battery with an emf of 6.00 V and negligible internal resistance. Find

(a) the initial rate of increase of current in the circuit,

(b) the rate of increase of current at the instant when the current is 0.500 A,

(c) the current 0.250 s after the circuit is closed,

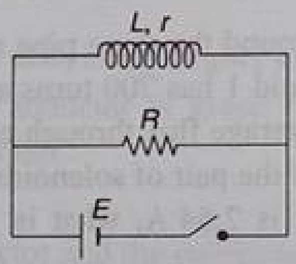
(d) the final steady state current.

25. A 35.0 V battery with negligible internal resistance, a 50.0 Ω resistor, and a 1.25 mH inductor with negligible resistance are all connected in series with an open switch. The switch is suddenly closed

(a) How long after closing the switch will the current through the inductor reach one-half of its maximum value?

(b) How long after closing the switch will the energy stored in the inductor reach one-half of its maximum value?

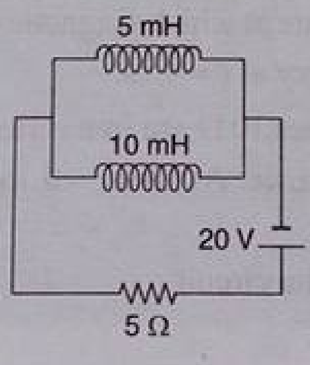
26. A solenoid of inductance L with resistance r is connected in parallel to a resistance R. A battery of emf E and of negligible internal resistance is connected across the parallel combination as shown in the figure. At time $t = 0$, switch S is opened, calculate



(a) current through the solenoid after the switch is opened.

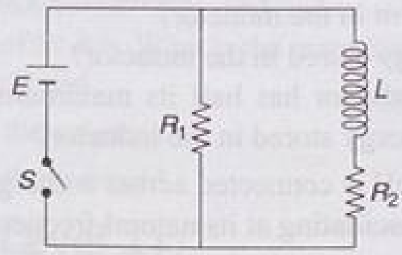
(b) amount of heat generated in the solenoid.

27. In the given circuit, find the current through the 5 mH inductor in steady state.

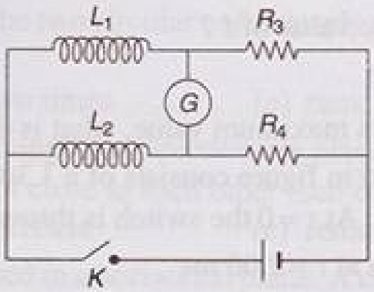


28. An inductor of inductance $L = 400$ mH and resistors $R_1 = 2\,\Omega$ and $R_2 = 2\,\Omega$ are connected to a battery of emf $E = 12$ V as shown in the figure. The internal resistance of the battery is negligible. The switch S is closed at time $t = 0$.

What is the potential drop across L as a function of time? After the steady state is reached, the switch is opened. What is the direction and the magnitude of current through R_1 as a function of time?

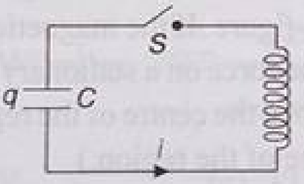


29. Two inductors of self-inductances L_1 and L_2 and of resistances R_1 and R_2 (not shown here) respectively, are connected in the circuit as shown in the figure. At the instant $t = 0$, key K is closed, obtain an expression for which the galvanometer will show zero deflection at all time after the key K is closed.



L–C Oscillations

30. In an oscillating L-C circuit in which $C = 4.00\ \mu F$, the maximum potential difference across the capacitor during the oscillations is 1.50 V and the maximum current through the inductor is 50.0 mA.
    (a) What is the inductance L?
    (b) What is the frequency of the oscillations?
    (c) How much time does the charge on the capacitor take to rise from zero to its maximum value?
31. In the L-C circuit shown, $C = 1\ \mu F$. With capacitor charged to 100 V, switch S is suddenly closed at time $t = 0$. The circuit then oscillates at 10^3 Hz.



    (a) Calculate ω and T
    (b) Express q as a function of time
    (c) Calculate L
    (d) Calculate the average current during the first quarter-cycle.
32. An L-C circuit consists of an inductor with $L = 0.0900$ H and a capacitor of $C = 4 \times 10^{-4}$ F. The initial charge on the capacitor is $5.00\ \mu C$, and the initial current in the inductor is zero.
    (a) What is the maximum voltage across the capacitor?

(b) What is the maximum current in the inductor?

(c) What is the maximum energy stored in the inductor?

(d) When the current in the inductor has half its maximum value, what is the charge on the capacitor and what is the energy stored in the inductor?

33. An inductor of inductance 2.0 mH is connected across a charged capactior of capacitance 5.0 μF, and resulting *L-C* circuit is set oscillating at its natural frequency. Let Q denote the instantaneous charge on the capacitor, and I the current in the circuit. It is found that the maximum value of Q is 200 μC.

(a) When $Q = 100\,\mu C$, what is the value of $\left|\dfrac{dI}{dt}\right|$

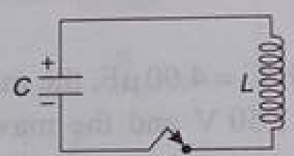
(b) When $Q = 200\,\mu C$, what is the value of I?

(c) Find the maximum value of I.

(d) When I is equal to one half its maximum value, what is the value of $|Q|$?

34. An *L-C* circuit like that illustrated in figure consists of a 3.30 H inductor and an 840 μF capacitor, initially carrying a 105 μC charge. At $t = 0$ the switch is thrown closed.

Compute the following quantities at $t = 2.00$ ms



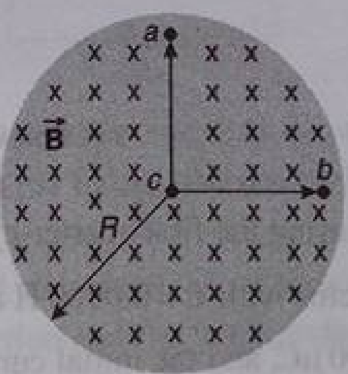
(a) the energy stored in the capacitor,

(b) the energy stored in the inductor,

(c) the total energy in the circuit.

Induced Electric Field

35. The magnetic field $\vec{\mathbf{B}}$ at all points within a circular region of radius R is uniform in space and directed into the plane of the page in figure. If the magnetic field is increasing at a rate dB/dt, what are the magnitude and direction of the force on a stationary positive point charge q located at points a, b and c? (Point a is a distance r above the centre of the region, point b is a distance r to the right of the centre, and point c is at the centre of the region.)



36. A long thin solenoid has 900 turns/metre and radius 2.50 cm. The current in the solenoid is increasing at a uniform rate of 60 A/s. What is the magnitude of the induced electric field at a point near the centre of the solenoid and

(a) 0.5 cm from the axis of the solenoid.

(b) 1.0 cm from the axis of the solenoid.

Objective Questions (Level 1)

Single Correct Option

1. The dimensions of self inductance are

(a) $[MLT^{-2}A^{-2}]$ (b) $[ML^2T^{-1}A^{-2}]$ (c) $[ML^2T^{-2}A^{-2}]$ (d) $[ML^2T^{-2}A^{-1}]$

2. When the number of turns in the two circular coils closely wound are doubled (in both) their mutual inductance becomes

(a) four times (b) two times (c) remains same (d) sixteen times

3. Two coils carrying current in opposite direction are placed co-axially with centres at some finite separation. If they are brought close to each other then current flowing in them should

(a) decrease (b) increase (c) remain same (d) become zero

4. A current carrying ring is placed in a horizontal plane. A charged particle is dropped along the axis of the ring to fall under the influence of gravity

(a) the current in the ring may increase

(b) the current in the ring may decrease

(c) the velocity of the particle will increase till it reaches the centre of the ring

(d) the acceleration of the particle will decrease continuously till it reaches the centre of the ring

5. Identify the incorrect statement. Induced electric field

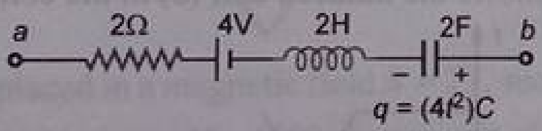
(a) is produced by varying magnetic field

(b) is non conservative in nature

(c) cannot exist in a region not occupied by magnetic field

(d) All of the above

6. In the figure shown V_{ab} at $t = 1$ s is



(a) 30 V (b) – 30 V (c) 20 V (d) – 20 V

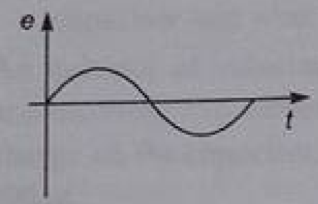
7. Two coils have a mutual inductance of 0.005 H. The current changes in the first coil according to equation $I = I_0 \sin \omega t$, where $I_0 = 10$A and $\omega = 100\pi$ rad/s. The maximum value of emf (in volt) in the second coil is

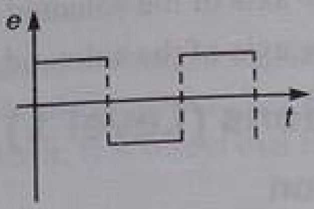
(a) 2π (b) 5π (c) π (d) 4π

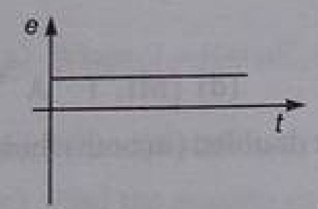
8. An inductance of 2 H carries a current of 2A. To prevent sparking when the circuit is broken a capacitor of 4 μF is connected across the inductance. The voltage rating of the capacitor is of the order of

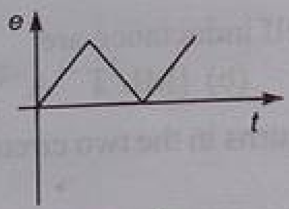
(a) 10^3 V (b) 10 V (c) 10^5 V (d) 10^6 V

9. A conducting rod is rotated about one end in a plane perpendicular to a uniform magnetic field with constant angular velocity. The correct graph between the induced emf (e) across the rod and time (t) is

(a) 

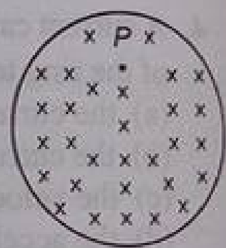
(b) 

(c) 

(d) 

10. A magnet is taken towards a conducting ring in such a way that a constant current of 10 mA is induced in it. The total resistance of the ring is $0.5\,\Omega$. In 5 s, the magnetic flux through the ring changes by
(a) 0.25 mWb (b) 25 mWb (c) 50 mWb (d) 15 mWb

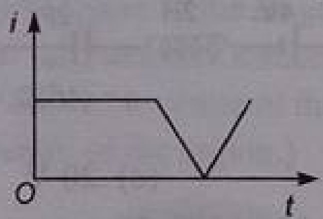
11. A uniform but increasing with time magnetic field exists in a cylindrical region. The direction of force on an electron at P is

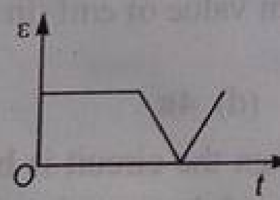


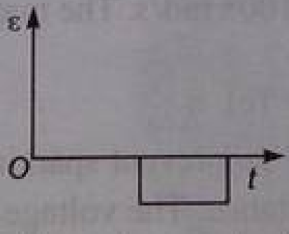
(a) towards right
(b) towards left
(c) into the plane of paper
(d) out of the plane of paper

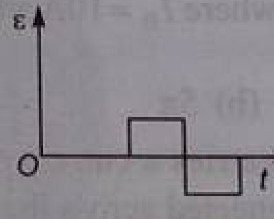
12. A magnetic flux through a stationary loop with a resistance R varies during the time interval τ as $\phi = at(\tau - t)$. Find the amount of heat generated in the loop during that time
(a) $\frac{a\tau^2}{2R}$ (b) $\frac{a^2\tau^3}{3R}$ (c) $\frac{2a^2\tau^3}{3R}$ (d) $\frac{a\tau}{3R}$

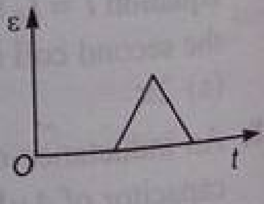
13. The current i in an induction coil varies with time t according to the graph shown in the figure. Which of the following graphs shows the induced emf (ε) in the coil with time



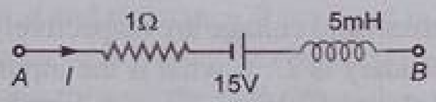
(a) 

(b) 

(c) 

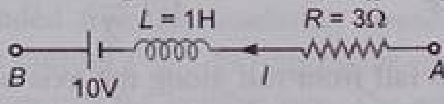
(d) 

14. The network shown in the figure is a part of complete circuit. What is the potential difference $V_B - V_A$ when the current I is 5 A and is decreasing at a rate of 10^3 A/s?



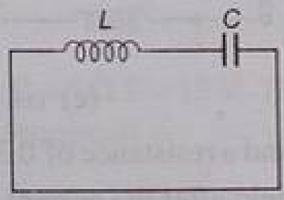
(a) 5 V (b) 10 V (c) 15 V (d) 20 V

15. In the given branch AB of a circuit a current $I = (10t + 5)$ A is flowing, where t is time in second. At $t = 0$, the potential difference between points A and B $(V_A - V_B)$ is



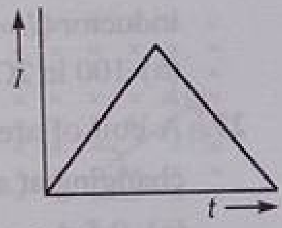
(a) 15 V (b) −5 V (c) −15 V (d) 5 V

16. In an LC circuit the capacitor has maximum charge q_0. The value of $\left(\frac{dI}{dt}\right)_{max}$ is

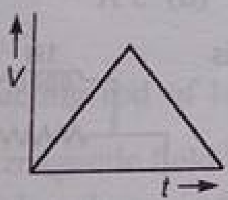


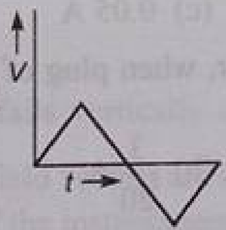
(a) $\frac{q_0}{LC}$ (b) $\frac{q_0}{\sqrt{LC}}$ (c) $\frac{q_0}{LC} - 1$ (d) $\frac{q_0}{LC} + 1$

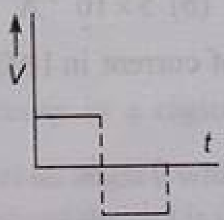
17. An alternating current I in an inductance coil varies with time t according to the graph as shown :

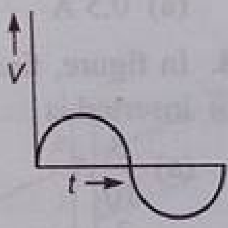


Which one of the following graphs gives the variation of voltage with time?

(a) 

(b) 

(c) 

(d) 

18. A loop of area 1 m^2 is placed in a magnetic field $B = 2T$, such that plane of the loop is parallel to the magnetic field. If the loop is rotated by 180°, the amount of net charge passing through any point of loop, if its resistance is 10 Ω is

(a) 0.4 C (b) 0.2 C (c) 0.8 C (d) 0 C

19. A rectangular loop of sides a and b is placed in x-y plane. A uniform but time varying magnetic field of strength $\vec{\mathbf{B}} = 20t\hat{\mathbf{i}} + 10t^2\hat{\mathbf{j}} + 50\hat{\mathbf{k}}$ is present in the region. The magnitude of induced emf in the loop at time t is

(a) $20 + 20t$ (b) 20 (c) $20t$ (d) zero

20. The armature of a DC motor has 20 Ω resistance. It draws a current of 1.5 amp when run by 200 V DC supply. The value of back emf induced in it will be

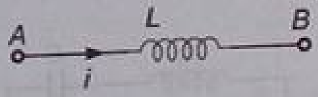
(a) 150 V (b) 170 V (c) 180 V (d) 190 V

21. In a transformer the output current and voltage are respectively 4 A and 20 V. If the ratio of number of turns in the primary to secondary is 2 : 1, what is the input current and voltage?
(a) 2 A and 40 V (b) 8 A and 10 V (c) 4 A and 10 V (d) 8 A and 40 V

22. When a loop moves towards a stationary magnet with speed v, the induced emf in the loop is E. If the magnet also moves away from the loop with the same speed, then the emf induced in the loop is
(a) E (b) $2E$ (c) $\frac{E}{2}$ (d) zero

23. A short magnet is allowed to fall from rest along the axis of a horizontal conducting ring. The distance fallen by the magnet in one second may be
(a) 5 m (b) 6 m (c) 4 m (d) None of these

24. In figure, if the current i decreases at a rate α, then $V_A - V_B$ is



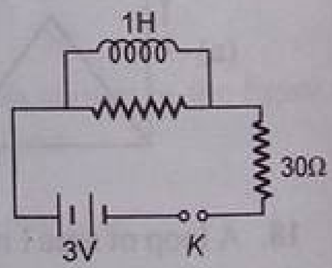
(a) zero (b) $-\alpha L$ (c) αL (d) No relation exists

25. A coil has an inductance of 50 mH and a resistance of 0.3 Ω. If a 12 V emf is applied across the coil, the energy stored in the magnetic field after the current has built up to its steady state value is
(a) 40 J (b) 40 mJ (c) 20 J (d) 20 mJ

26. A constant voltage is applied to a series R-L circuit by closing the switch. The voltage across inductor ($L = 2$H) is 20 V at $t = 0$ and drops to 5 V at 20 ms. The value of R in Ω is
(a) 100 ln 2Ω (b) 100 (1 – ln 2) Ω (c) 100 ln 4Ω (d) 100(1 – ln 4)

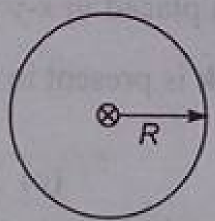
27. A coil of area 10 cm^2 and 10 turns is in magnetic field directed perpendicular to the plane and changing at a rate of 10^8 gauss/s. The resistance of coil is 20 Ω. The current in the coil will be
(a) 0.5 A (b) 5×10^{-3} A (c) 0.05 A (d) 5 A

28. In figure, final value of current in 10 Ω resistor, when plug of key K is inserted is



(a) $\frac{3}{10}$ A (b) $\frac{3}{20}$ A
(c) $\frac{3}{11}$ A (d) zero

29. A circuit consists of a circular loop of radius R kept in the plane of paper and an infinitely long current carrying wire kept perpendicular to the plane of paper and passing through the centre of loop. The mutual inductance of wire and loop will be

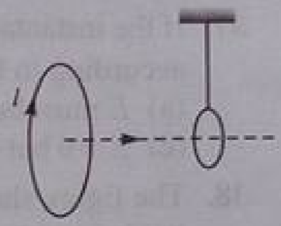


(a) $\frac{\mu_0 \pi R}{2}$ (b) 0 (c) $\mu_0 \pi R^2$ (d) $\frac{\mu_0 R^2}{2}$

30. A flat circular coil of n turns, area A and resistance R is placed in a uniform magnetic field B. The plane of coil is initially perpendicular to B. When the coil is rotated through an angle of 180° about one of its diameter, a charge Q_1 flows through the coil. When the same coil after being brought to its initial position, is rotated through an angle of 360° about the same axis a charge Q_2 flows through it. Then Q_2/Q_1 is

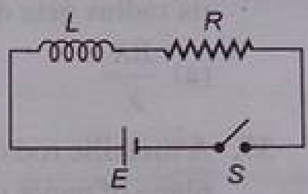
(a) 1 (b) 2 (c) 1/2 (d) 0

31. A small circular loop is suspended from an insulating thread. Another co-axial circular loop carrying a current I and having radius much larger than the first loop starts moving towards the smaller loop. The smaller loop will



(a) be attracted towards the bigger loop
(b) be repelled by the bigger loop
(c) experience no force
(d) All of the above

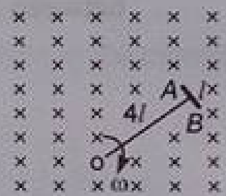
32. In the circuit shown in figure, $L = 10\text{H}$, $R = 5\,\Omega$ $E = 15$ V. The switch S is closed at $t = 0$. At $t = 2$ s, the current in the circuit is



(a) $3\left(1-\frac{1}{e}\right)$A (b) $3\left(1-\frac{1}{e^2}\right)$A

(c) $3\left(\frac{1}{e}\right)$A (d) $3\left(\frac{1}{e^2}\right)$A

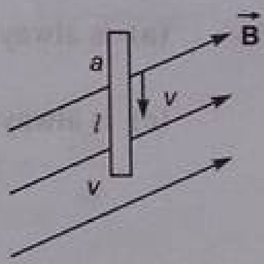
33. In the figure shown, a T-shaped conductor moves with constant angular velocity ω in a plane perpendicular to uniform magnetic field $\vec{B}$. The potential difference $V_A - V_B$ is



(a) zero (b) $\frac{1}{2}B\omega l^2$

(c) $2B\omega l^2$ (d) $B\omega l^2$

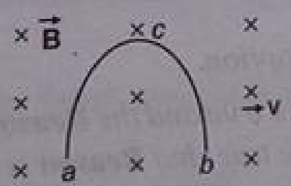
34. A conducting rod of length l falls vertically under gravity in a region of uniform magnetic field $\vec{B}$. The field vectors are inclined at an angle θ with the horizontal as shown in figure. If the instantaneous velocity of the rod is v, the induced emf in the rod ab is



(a) Blv (b) $Blv\cos\theta$

(c) $Blv\sin\theta$ (d) zero

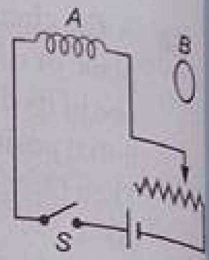
35. A semi-circular conducting ring acb of radius R moves with constant speed v in a plane perpendicular to uniform magnetic field B as shown in figure. Identify the correct statement



(a) $V_a - V_c = BRv$ (b) $V_b - V_c = BRv$

(c) $V_a - V_b = 0$ (d) None of these

36. The ring B is coaxial with a solenoid A as shown in figure. As the switch S is closed at $t = 0$, the ring B



(a) is attracted towards A
(b) is repelled by A
(c) is initially repelled and then attracted
(d) is initially attracted and then repelled

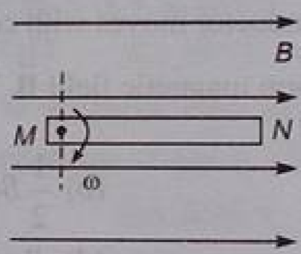
37. If the instantaneous magnetic flux and induced emf produced in a coil is ϕ and E respectively, then according to Faraday's law of electro magnetic induction

(a) E must be zero if $\phi = 0$
(b) $E \neq 0$ if $\phi = 0$
(c) $E \neq 0$ but ϕ may or may not be zero
(d) $E = 0$ then ϕ must be zero

38. The figure shows a conducting ring of radius R. A uniform steady magnetic field B lies perpendicular to the plane of the ring in a circular region of radius $r\,(< R)$. If the resistance per unit length of the ring is λ, then the current induced in the ring when its radius gets doubled is

(a) $\dfrac{BR}{\lambda}$
(b) $\dfrac{2BR}{\lambda}$
(c) zero
(d) $\dfrac{Br^2}{4R\lambda}$

39. A metallic rod of length l is hinged at the point M and is rotating about an axis perpendicular to the plane of paper with a constant angular velocity ω. A uniform magnetic field of intensity B is acting in the region (as shown in the figure) parallel to the plane of paper. The potential difference between the points M and N



(a) is always zero
(b) varies between $\frac{1}{2}B\omega l^2$ to 0
(c) is always $\frac{1}{2}B\omega l^2$
(d) is always $B\omega l^2$

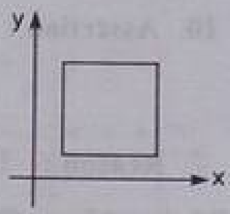
JEE Corner

Assertion and Reason

Directions : *Choose the correct option.*

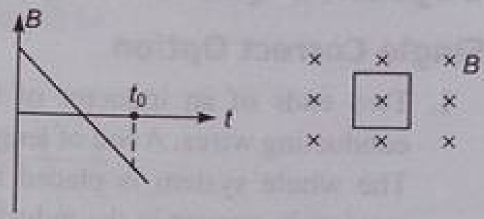
(a) *If both **Assertion** and **Reason** are true and the **Reason** is correct explanation of the **Assertion**.*
(b) *If both **Assertion** and **Reason** are true; but **Reason** is not the correct explanation of **Assertion**.*
(c) *If **Assertion** is true, but the **Reason** is false.*
(d) *If **Assertion** is false, but the **Reason** is true.*

1. Assertion : A square loop is placed in x-y plane as shown in figure. Magnetic field in the region is $\vec{\mathbf{B}} = -B_0 x\,\hat{\mathbf{k}}$. The induced current in the loop is anticlockwise.



Reason : If inward magnetic field from such a loop increases, then current should be anticlockwise.

2. Assertion : Magnetic field B (shown inwards) varies with time t as shown. At time t_0 induced current in the loop is clockwise.



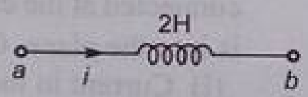
Reason : If rate of change of magnetic flux from a coil is constant, charge should flow in the coil at a constant rate.

3. Assertion : Electric field produced by a variable magnetic field can't exert a force on a charged particle.

Reason : This electric field is non-conservative in nature.

4. Assertion : Current flowing in the circuit is :

$$i = 2t - 8$$



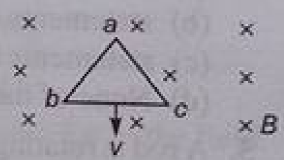
At $t = 1$ s, $V_a - V_b = +4$ V

Reason : $V_a - V_b$ is $+4$ V all the time.

5. Assertion : Angular frequency of L-C oscillations is 2 rad/s and maximum current in the circuit is 1 A. Then, maximum rate of change of current should be 2 A/s.

Reason : $\left(\dfrac{dI}{dt}\right)_{\max} = (I_{\max})\omega.$

6. Assertion : A conducting equilateral loop abc is moved translationally with constant speed v in uniform inward magnetic field B as shown. Then : $V_a - V_b = V_b - V_c$.



Reason : Point a is at higher potential than point b.

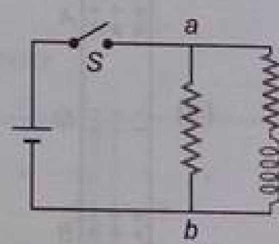
7. Assertion : Motional induced emf $e = Bvl$ can be derived from the relation $e = -\dfrac{d\phi}{dt}$.

Reason : Lenz law is a consequence of law of conservation of energy.

8. Assertion : If some ferromagnetic substance is filled inside a solenoid, its coefficient of selt induction L will increase.

Reason : By increasing the current in a coil its coefficient of self induction L can be increased.

9. Assertion : In the circuit shown in figure, current in wire ab will become zero as soon as switch is opened.



Reason : A resistance does not oppose increase or decrease of current through it.

10. Assertion : In parallel, current distributes in inverse ratio of inductance.

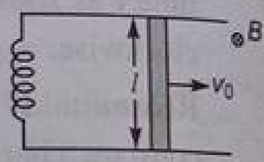
$$i \propto \frac{1}{L}$$

Reason : In electrical circuits an inductor can be treated as a resistor.

Objective Questions (Level 2)

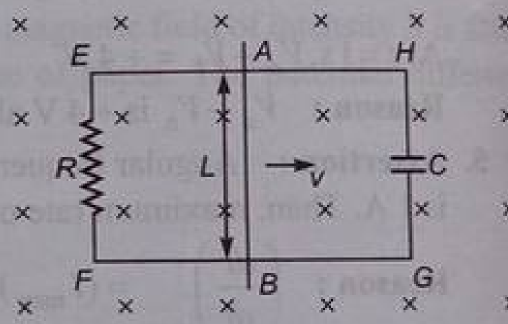
Single Correct Option

1. Two ends of an inductor of inductance L are connected to two parallel conducting wires. A rod of length l and mass m is given velocity v_0 as shown. The whole system is placed in perpendicular magnetic field B. Find the maximum current in the inductor. (neglect gravity and friction)



(a) $\frac{mv_0}{L}$ (b) $\sqrt{\frac{m}{L}}v_0$ (c) $\frac{mv_0^2}{L}$ (d) None of these

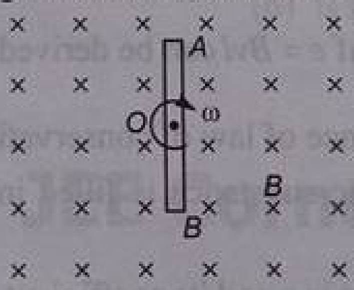
2. A conducting rod is moving with a constant velocity v over the parallel conducting rails which are connected at the ends through a resistor R and capacitor C as shown in the figure. Magnetic field B is into the plane. Consider the following statements

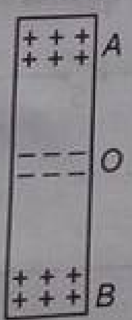


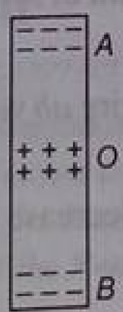
(i) Current in loop $AEFBA$ is anticlockwise
(ii) Current in loop $AEFBA$ is clockwise
(iii) Current through the capacitor is zero
(iv) Energy stored in the capacitor is $\frac{1}{2}CB^2L^2v^2$

Which of the following options is correct?
(a) statements (i) and (iii) are correct
(b) statements (ii) and (iv) are correct
(c) statements (i), (iii) and (iv) are correct
(d) None of the above

3. A rod is rotating with a constant angular velocity ω about point O (its centre) in a magnetic field B as shown. Which of the following figure correctly shows the distribution of charge inside the rod?



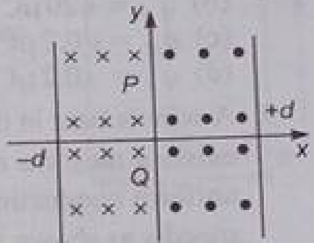
(a)


(b)


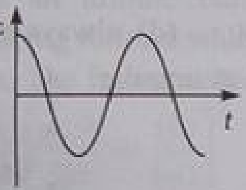
(c)


(d)

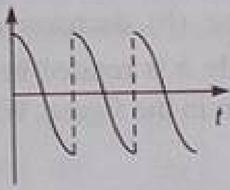

4. A straight conducting rod PQ is executing SHM in xy plane from $x = -d$ to $x = +d$. Its mean position is $x = 0$ and its length is along y-axis. There exists a uniform magnetic field B from $x = -d$ to $x = 0$ pointing inward normal to the paper and from $x = 0$ to $= +d$ there exists another uniform magnetic field of same magnitude B but pointing outward normal to the plane of the paper. At the instant $t = 0$, the rod is at $x = 0$ and moving to the right. The induced emf (ε) across the rod PQ vs time (t) graph will be



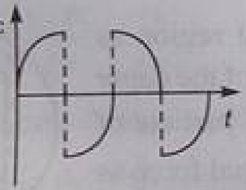
(a)



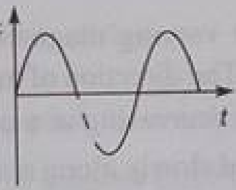
(b)



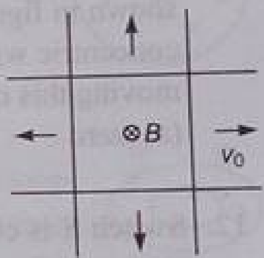
(c)



(d)



5. Two parallel long straight conductors lie on a smooth plane surface. Two other parallel conductors rest on them at right angles so as to form a square of side a. A uniform magnetic field B exists at right angles to the plane containing the conductors. Now conductors start moving outward with a constant velocity v_0 at $t = 0$. Then induced current in the loop at any time t is (λ is resistance per unit length of the conductors)

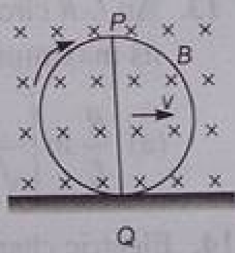


(a) $\dfrac{aBv_0}{\lambda(a + v_0 t)}$ (b) $\dfrac{aBv_0}{2\lambda}$ (c) $\dfrac{Bv_0}{\lambda}$ (d) $\dfrac{Bv_0}{2\lambda}$

6. A conducting square loop is placed in a magnetic field B with its plane perpendicular to the field. Some how the sides of the loop start shrinking at a constant rate α. The induced emf in the loop at an instant when its side is a, is

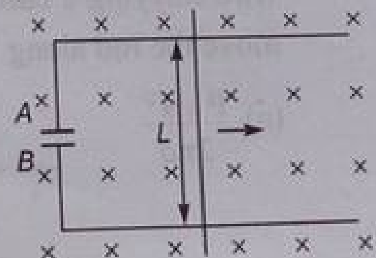
(a) $2a\alpha B$ (b) $a^2\alpha B$ (c) $2a^2\alpha B$ (d) $a\alpha B$

7. A conducting straight wire PQ of length l is fixed along a diameter of a non-conducting ring as shown in the figure. The ring is given a pure rolling motion on a horizontal surface such that its centre of mass has a velocity v. There exists a uniform horizontal magnetic field B in horizontal direction perpendicular to the plane of ring. The magnitude of induced emf in the wire PQ at the position shown in the figure will be



(a) Bvl (b) $2Bvl$ (c) $3Bvl/2$ (d) zero

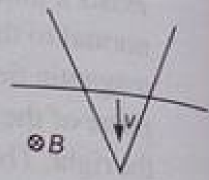
8. A conducting rod of length $L = 0.1$ m is moving with a uniform speed $v = 0.2$ m/s on conducting rails in a magnetic field $B = 0.5$ T as shown. On one side, the end of the rails is connected to a capacitor of capacitance $C = 20\,\mu$F. Then the charges on the capacitor plates are



(a) $q_A = 0 = q_B$

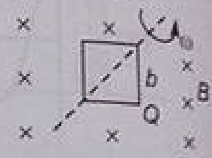
(b) $q_A = +20\,\mu C$ and $q_B = -20\,\mu C$
(c) $q_A = +0.2\,\mu C$ and $q_B = -0.2\,\mu C$
(d) $q_A = -0.2\,\mu C$ and $q_B = -0.2\,\mu C$

9. A wire is bent in the form of a V shape and placed in a horizontal plane. There exists a uniform magnetic field B perpendicular to the plane of the wire. A uniform conducting rod starts sliding over the V shaped wire with a constant speed v as shown in the figure. If the wire has no resistance, the current in rod will



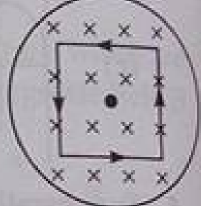
(a) increase with time (b) decrease with time (c) remain constant (d) always be zero

10. A square loop of side b is rotated in a constant magnetic field B at angular frequency ω as shown in the figure. What is the emf induced in it?



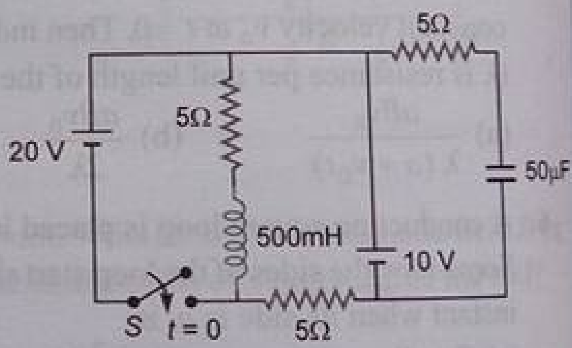
(a) $b^2 B\omega \sin \omega t$ (b) $bB\omega \sin^2 \omega t$
(c) $bB^2 \omega \cos \omega t$ (d) $b^2 B\omega$

11. A uniform but time varying magnetic field exists in a cylindrical region as shown in the figure. The direction of magnetic field is into the plane of the paper and its magnitude is decreasing at a constant rate of 2×10^{-3} T/s. A particle of charge 1 μC is moved slowly along a square of side 1 m by an external force as shown in figure. The plane of the square lies in the plane of the paper and it is concentric with the cylindrical region. The work done by the external force in moving this charge along the square will be



(a) zero (b) 2×10^{-9} J (c) 4×10^{-9} J (d) 1.0×10^{-6} J

12. Switch S is closed at $t = 0$, in the circuit shown. The change in flux in the inductor ($L = 500$ mH) from $t = 0$ to an instant when it reaches steady state is



(a) 2 Wb
(b) 1.5 Wb
(c) 0 Wb
(d) None

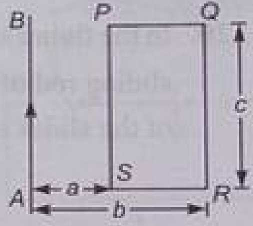
13. An L-R circuit is connected to a battery at time $t = 0$. The energy stored in the inductor reaches half its maximum value at time

(a) $\frac{R}{L} \ln\left[\frac{\sqrt{2}}{\sqrt{2}-1}\right]$ (b) $\frac{L}{R} \ln\left[\frac{\sqrt{2}-1}{\sqrt{2}}\right]$ (c) $\frac{L}{R} \ln\left(\frac{\sqrt{2}}{\sqrt{2}-1}\right)$ (d) $\frac{R}{L} \ln\left[\frac{\sqrt{2}-1}{\sqrt{2}}\right]$

14. Electric charge q is distributed uniformly over a rod of length l. The rod is placed parallel to a long wire carrying a current i. The separation between the rod and the wire is a. The force needed to move the rod along its length with a uniform velocity v is

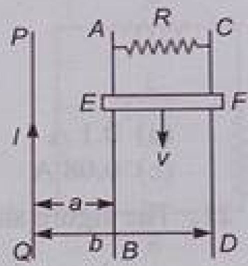
(a) $\frac{\mu_0 iqv}{2\pi a}$ (b) $\frac{\mu_0 iqv}{4\pi a}$ (c) $\frac{\mu_0 iqvl}{2\pi a}$ (d) $\frac{\mu_0 iqvl}{4\pi a}$

15. AB is an infinitely long wire placed in the plane of rectangular coil of dimensions as shown in the figure. Calculate the mutual inductance of wire AB and coil $PQRS$



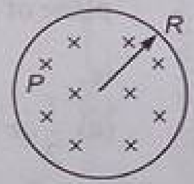
(a) $\frac{\mu_0 b}{2\pi} \ln \frac{a}{b}$
(b) $\frac{\mu_0 c}{2\pi} \ln \frac{b}{a}$
(c) $\frac{\mu_0 abc}{2\pi(b-a)^2}$
(d) None of these

16. PQ is an infinite current carrying conductor. AB and CD are smooth conducting rods on which a conductor EF moves with constant velocity v as shown. The force needed to maintain constant speed of EF is



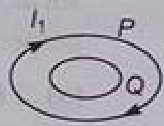
(a) $\frac{1}{vR}\left[\frac{\mu_0 Iv}{2\pi} \ln \frac{(b)}{(a)}\right]^2$
(b) $\frac{v}{R}\left[\frac{\mu_0 Iv}{2\pi} \ln \frac{(a)}{(b)}\right]^2$
(c) $\frac{v}{R}\left[\frac{\mu_0 Iv}{2\pi} \ln \frac{(b)}{(a)}\right]^2$
(d) None of these

17. The figure shows a circular region of radius R occupied by a time varying magnetic field $\vec{\mathbf{B}}(t)$ such that $\frac{dB}{dt} < 0$. The magnitude of induced electric field at the point P at a distance $r < R$ is



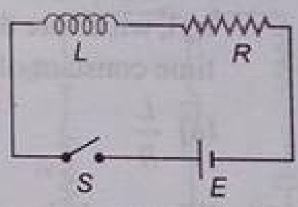
(a) decreasing with r
(b) increasing with r
(c) not varying with r
(d) varying as r^{-2}

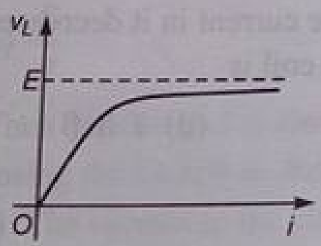
18. Two circular loops P and Q are concentric and coplanar as shown in figure. The loop Q is smaller than P. If the current I_1 flowing in loop P is decreasing with time, then the current I_2 in the loop Q

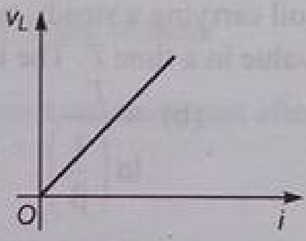


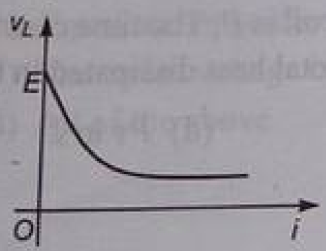
(a) flows in the same direction as that of P
(b) flows in the opposite direction as that of Q
(c) is zero
(d) None of these

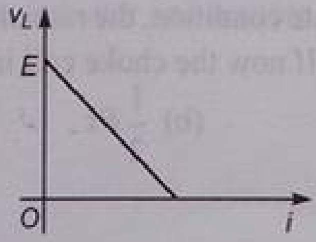
19. In the circuit shown in figure the switch S is closed at $t = 0$. If v_L is the voltage induced across the inductor and i is the instantaneous current, the correct variation of v_L versus i is given by



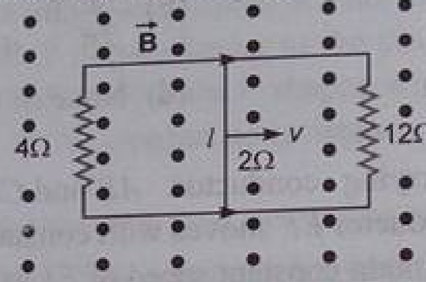
(a)


(b)


(c)


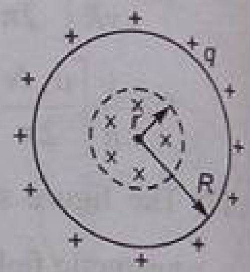
(d)


20. In the figure shown, a uniform magnetic field $|\vec{B}| = 0.5$ T is perpendicular to the plane of circuit. The sliding rod of length $l = 0.25$ m moves uniformly with constant speed $v = 4\ \text{ms}^{-1}$. If the resistance of the slides is 2Ω, then the current flowing through the sliding rod is



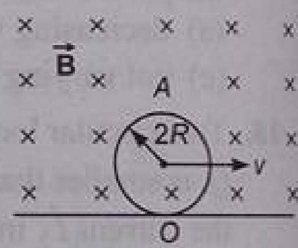
(a) 0.1 A
(b) 0.17 A
(c) 0.08 A
(d) 0.03 A

21. The figure shows a non-conducing ring of radius R carrying a charge q. In a circular region of radius r, a uniform magnetic field $\vec{B}$ perpendicular to the plane of the ring varies at a constant rate $\frac{dB}{dt} = \beta$. The torque acting on the ring is



(a) $\frac{1}{2} q r^2 \beta$
(b) $\frac{1}{2} q R^2 \beta$
(c) $q r^2 \beta$
(d) zero

22. A conducting ring of radius $2R$ rolls on a smooth horizontal conducting surface as shown in figure. A uniform horizontal magnetic field B is perpendicular to the plane of the ring. The potential of A with respect to O is



(a) $2 BvR$
(b) $\frac{1}{2} BvR$
(c) $8 BvR$
(d) $4 BvR$

23. A uniformly wound long solenoid of inductance L and resistance R is cut into two parts in the ratio $\eta : 1$, which are then connected in parallel. The combination is then connected to a cell of emf E. The time constant of the circuit is

(a) $\frac{L}{R}$
(b) $\frac{L}{(\eta+1)R}$
(c) $\left(\frac{\eta}{\eta+1}\right)\frac{L}{R}$
(d) $\left(\frac{\eta+1}{\eta}\right)\frac{L}{R}$

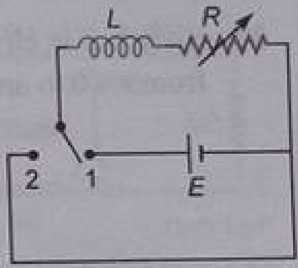
24. When a choke coil carrying a steady current is short circuited, the current in it decreases to $\beta\ (<1)$ times its initial value in a time T. The time constant of the choke coil is

(a) $\frac{T}{\beta}$
(b) $\frac{T}{\ln\left(\frac{1}{\beta}\right)}$
(c) $\frac{T}{\ln \beta}$
(d) $T \ln \beta$

25. In the steady state condition, the rate of heat produced in a choke coil is P. The time constant of the choke coil is τ. If now the choke coil is short circuited, then the total heat dissipated in the coil is

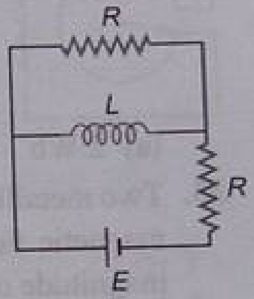
(a) $P\tau$
(b) $\frac{1}{2} P\tau$
(c) $\frac{P\tau}{\ln 2}$
(d) $P\tau \ln 2$

26. In the circuit shown in figure initially the switch is in position 1 for a long time, then suddenly at $t = 0$, the switch is shifted to position 2. It is required that a constant current should flow in the circuit, the value of resistance R in the circuit



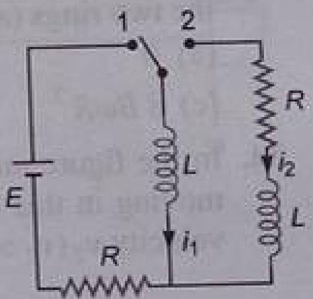
(a) should be decreased at a constant rate
(b) should be increased at a constant rate
(c) should be maintained constant
(d) Not possible

27. The figure shows an L-R circuit, the time constant for the circuit is



(a) $\frac{L}{2R}$ (b) $\frac{2L}{R}$
(c) $\frac{2R}{L}$ (d) $\frac{R}{2L}$

28. In figure, the switch is in the position 1 for a long time, then the switch is shifted to position 2 at $t = 0$. At this instant the value of i_1 and i_2 are

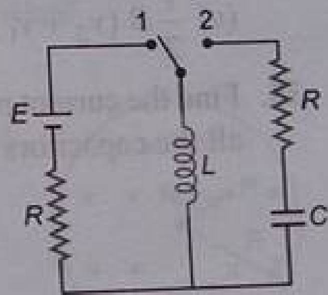


(a) $\frac{E}{R}, 0$ (b) $\frac{E}{R}, \frac{-E}{R}$
(c) $\frac{E}{2R}, \frac{-E}{2R}$ (d) None of these

29. In a decaying L-R circuit, the time after which energy stored in the inductor reduces to one-fourth of its initial value is

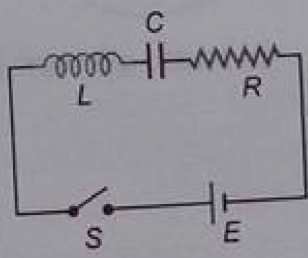
(a) $(\ln 2)\frac{L}{R}$ (b) $0.5\frac{L}{R}$ (c) $\sqrt{2}\frac{L}{R}$ (d) $\left(\frac{\sqrt{2}}{\sqrt{2}-1}\right)\frac{L}{R}$

30. Initially, the switch is in position 1 for a long time and then shifted to position 2 at $t = 0$ as shown in figure. Just after closing the switch, the magnitude of current through the capacitor is



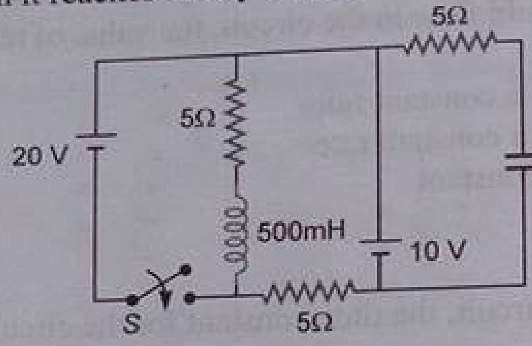
(a) zero (b) $\frac{E}{2R}$
(c) $\frac{E}{R}$ (d) None of these

31. When the switch S is closed at $t = 0$, identify the correct statement just after closing the switch as shown in figure



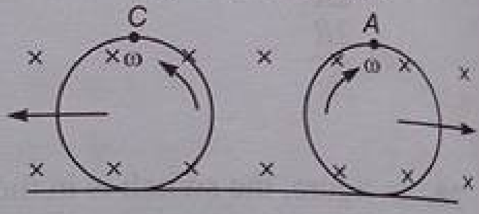
(a) The current in the circuit is maximum
(b) Equal and opposite voltages are dropped across inductor and resistor
(c) The entire voltage is dropped across inductor
(d) All of the above

32. Switch S is closed at $t=0$, in the circuit shown. The change in flux in the inductor ($L = 500$ mH) from $t=0$ to an instant when it reaches steady state is



(a) 2 Wb (b) 1.5 Wb (c) 0 Wb (d) None of these

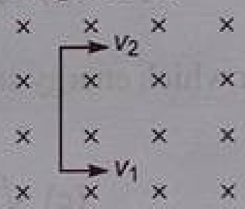
33. Two metallic rings of radius R are rolling on a metallic rod. A magnetic field of magnitude B is applied in the region. The magnitude of potential difference between points A and C on the two rings (as shown), will be



(a) 0 (b) $4B\omega R^2$

(c) $8B\omega R^2$ (d) $2B\omega R^2$

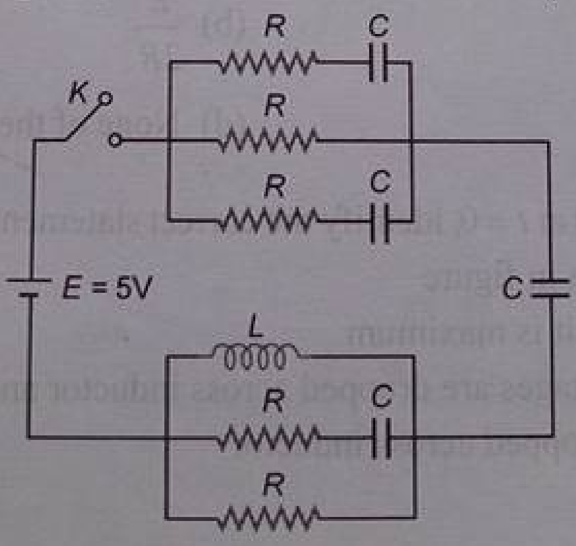
34. In the figure magnetic field points into the plane of paper and the conducting rod of length l is moving in this field such that the lowest point has a velocity v_1 and the topmost point has the velocity $v_2 (v_2 > v_1)$. The emf induced is given by



(a) $Bv_1 l$ (b) $Bv_2 l$

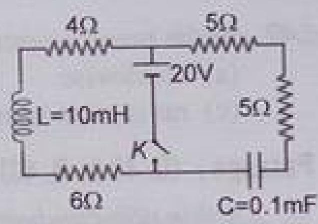
(c) $\frac{1}{2}B(v_2 + v_1)l$ (d) $\frac{1}{2}B(v_2 - v_1)l$

35. Find the current passing through battery immediately after key (K) is closed. It is given that initially all the capacitors are uncharged. (Given that $R = 6\Omega$ and $C = 4\mu$F)



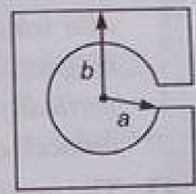
(a) 1 A (b) 5 A (c) 3 A (d) 2 A

36. In the circuit shown, the key (K) is closed at $t = 0$, the current through the key at the instant $t = 10^{-3} \ln 2$, is



(a) 2 A (b) 8 A
(c) 4 A (d) zero

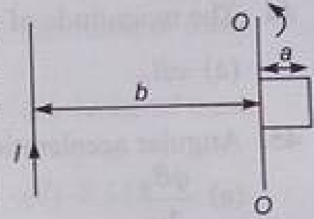
37. A loop shown in the figure is immersed in the varying magnetic field $B = B_0 t$, directed into the page. If the total resistance of the loop is R, then the direction and magnitude of induced current in the inner circle is



(a) clockwise $\dfrac{B_0(\pi a^2 - b^2)}{R}$ (b) anticlockwise $\dfrac{B_0\pi(a^2 + b^2)}{R}$

(c) clockwise $\dfrac{B_0(\pi a^2 + 4b^2)}{R}$ (d) clockwise $\dfrac{B_0(4b^2 - \pi a^2)}{R}$

38. A square loop of side a and a straight long wire are placed in the same plane as shown in figure. The loop has a resistance R and inductance L. The frame is turned through 180° about the axis OO'. What is the electric charge that flows through the loop?



(a) $\dfrac{\mu_0 Ia}{2\pi R} \ln\left(\dfrac{2a+b}{b}\right)$ (b) $\dfrac{\mu_0 Ia}{2\pi R} \ln\left(\dfrac{b}{b^2 - a^2}\right)$

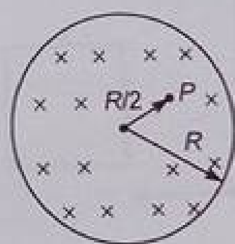
(c) $\dfrac{\mu_0 Ia}{2\pi R} \ln\left(\dfrac{a+2b}{b}\right)$ (d) None of these

39. A flat coil of area A and n turns is placed at the centre of ring of radius r ($r^2 >> A$) and resistance R. The two are coplanar. When current in the coil increases from zero to i, the total charge circulating in the ring is

(a) $\dfrac{\mu_0 nAi}{2rR}$ (b) $\dfrac{\mu_0 n^2 Ai}{2rR}$ (c) $\dfrac{\mu_0 nAi}{2\pi r}$ (d) $\dfrac{\mu_0 n^2 i}{4\pi rR}$

Passage : (Q. 40 to Q. 42)

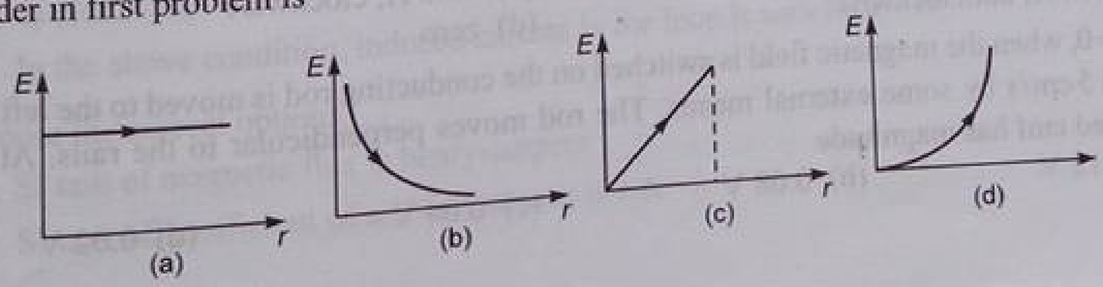
A uniform but time varying magnetic field $B = (2t^3 + 24t)$ T is present in a cylindrical region of radius $R = 2.5$ cm as shown in figure.



40. The force on an electron at P at $t = 2.0$ s is

(a) 96×10^{-21} N (b) 48×10^{-21} N
(c) 24×10^{-21} N (d) zero

41. The variation of electric field at any instant as a function of distance measured from the centre of cylinder in first problem is



42. In the previous problem, the direction of circular electric lines at $t = 1$ s is
(a) clockwise
(b) anticlockwise
(c) no current is induced
(d) cannot be predicted

Passage : (Q. 43 to Q. 46)

A thin non-conducting ring of mass m, radius a carrying a charge q can rotate freely about its own axis which is vertical. At the initial moment the ring was at rest in horizontal position and no magnetic field was present. At instant $t = 0$, a uniform magnetic field is switched on which is vertically downward and increases with time according to the law $B = B_0 t$. Neglecting magnetism induced due to rotational motion of ring.

43. The magnitude of induced emf on the closed surface of ring will be
(a) $\pi a^2 B_0$
(b) $2a^2 B_0$
(c) zero
(d) $\frac{1}{2}\pi a^2 B_0$

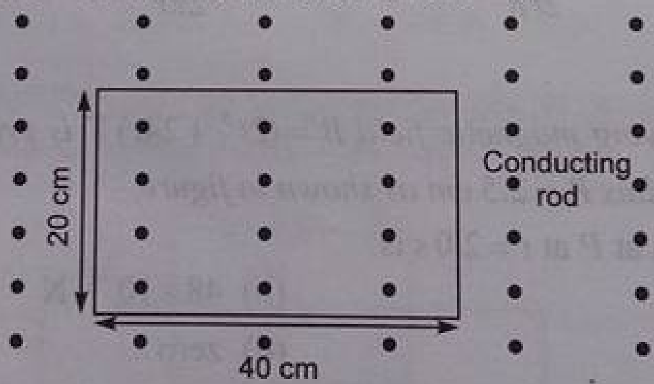
44. The magnitude of an electric field on the circumference of the ring is
(a) aB_0
(b) $2aB_0$
(c) $\frac{1}{2}aB_0$
(d) zero

45. Angular acceleration of ring is
(a) $\frac{qB_0}{2m}$
(b) $\frac{qB_0}{4m}$
(c) $\frac{qB_0}{m}$
(d) $\frac{2qB_0}{m}$

46. Find instantaneous power developed by electric force acting on the ring at $t = 1$ s
(a) $\frac{2q^2B_0^2a^2}{14m}$
(b) $\frac{q^2B_0^2a^2}{8m}$
(c) $\frac{3q^2B_0^2a^2}{m}$
(d) $\frac{q^2B_0^2a^2}{4m}$

Passage : (Q. 47 to Q. 49)

Figure shows a conducting rod of negligible resistance that can slide on smooth U-shaped rail made of wire of resistance $1\,\Omega/\text{m}$. Position of the conducting rod at $t = 0$ is shown. A time dependent magnetic field $B = 2t$ tesla is switched on at $t = 0$.



47. The current in the loop at $t = 0$ due to induced emf is
(a) 0.16 A, clockwise
(b) 0.08 A, clockwise
(c) 0.16 A, anticlockwise
(d) zero

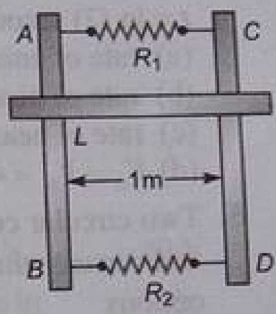
48. At $t = 0$, when the magnetic field is switched on the conducting rod is moved to the left at constant speed 5 cm/s by some external means. The rod moves perpendicular to the rails. At $t = 2$ s, net induced emf has magnitude
(a) 0.12 V
(b) 0.08 V
(c) 0.04 V
(d) 0.02 V

49. The magnitude of the force required to move the conducting rod at constant speed 5 cm/s at the same instant $t = 2$s, is equal to

(a) 0.096 N (b) 0.12 N (c) 0.08 N (d) 0.064 N

Passage : (Q. 50 to Q. 52)

Two parallel vertical metallic rails AB and CD are separated by 1 m. *They are connected at the two ends by resistances* R_1 *and* R_2 *as shown in the figure. A horizontal metallic bar L of mass* 0.2 kg *slides without friction, vertically down the rails under the action of gravity. There is a uniform horizontal magnetic field of* 0.6 T *perpendicular to the plane of the rails. It is observed that when the terminal velocity is attained, the powers dissipated in* R_1 *and* R_2 *are* 0.76 W *and* 1.2 W *respectively* ($g = 9.8\ m/s^2$)



50. The terminal velocity of the bar L will be

(a) 2 m/s (b) 3 m/s (c) 1 m/s (d) None of these

51. The value of R_1 is

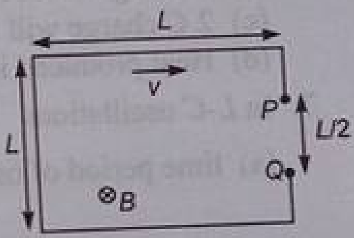
(a) 0.47 Ω (b) 0.82 Ω (c) 0.12 Ω (d) None of these

52. The value of R_2 is

(a) 0.6 Ω (b) 0.5 Ω (c) 0.4 Ω (d) 0.3 Ω

More than One Correct Options

1. The loop shown moves with a velocity v in a uniform magnetic field of magnitude B, directed into the paper. The potential difference between points P and Q is e. Then



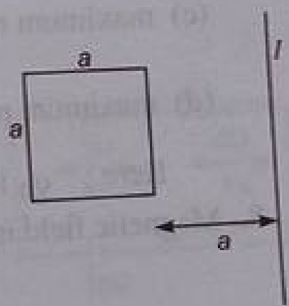
(a) $e = \frac{1}{2} BLv$

(b) $e = BLv$

(c) P is positive with respect to Q

(d) Q is positive with respect to P

2. In infinitely long wire is placed near a square loop as shown in figure. Choose the correct options



(a) The mutual inductance between the two is $\frac{\mu_0 a}{2\pi} \ln(2)$

(b) The mutual inductance between the two is $\frac{\mu_0 a^2}{2\pi} \ln(2)$

(c) If a constant current is passed in the straight wire in upward direction and loop is brought close to the wire then induced current in the loop is clockwise

(d) In the above condition, induced current in the loop is anticlockwise

3. Choose the correct options

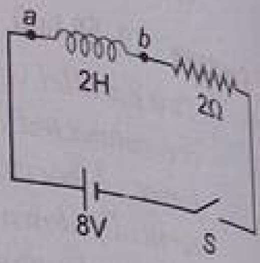
(a) SI unit of magnetic flux is henry-ampere

(b) SI unit of coefficient of self-inductance is J/A

(c) SI unit of coefficient of self inductance is $\frac{\text{volt-second}}{\text{ampere}}$

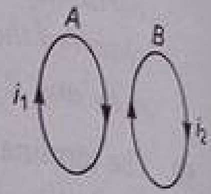
(d) SI unit of magnetic induction is weber

4. In the circuit shown in figure, circuit is closed at time $t = 0$. At time $t = \ln(2)$ second



(a) rate of energy supplied by the battery is 16 J/s
(b) rate of heat dissipated across resistance is 8 J/s
(c) rate of heat dissipated across resistance is 16 J/s
(d) $V_a - V_b = 4$ V

5. Two circular coils are placed adjacent to each other. Their planes are parallel and currents through them i_1 and i_2 are in same directions. Choose the correct options



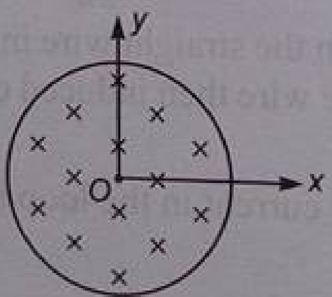
(a) When A is brought near B, current i_2 will decrease
(b) In the above process, current i_2 will increase
(c) When current i_1 is increased, current i_2 will decrease
(d) In the above process, current i_2 will increase

6. A coil of area $2m^2$ and resistance 4Ω is placed perpendicular to a uniform magnetic field of 4 T. The loop is rotated by 90° in 0.1 second. Choose the correct options.
(a) Average induced emf in the coil is 8 V
(b) Average induced current in the circuit is 20 A
(c) 2 C charge will flow in the coil in above period
(d) Heat produced in the coil in the above period can't be determined from the given data

7. In L-C oscillations
(a) time period of oscillations is $\frac{2\pi}{\sqrt{LC}}$
(b) maximum current in circuit is $\frac{q_0}{\sqrt{LC}}$
(c) maximum rate of change of current in circuit is $\frac{q_0}{LC}$
(d) maximum potential difference across the inductor is $\frac{q_0}{2C}$

Here : q_0 is maximum charge on capacitor.

8. Magnetic field in a cylindrical region of radius R in inward direction is as shwon in figure

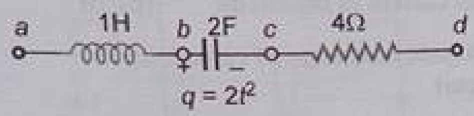


(a) an electron will experience no force kept at $(2R, 0, 0)$ if magnetic field increases with time
(b) in the above situation, electron will experience the force in negative y-axis

(c) If a proton is kept at $\left(0, \frac{R}{2}, 0\right)$ and magnetic field is decreasing, then it will experience the force in positive x-direction

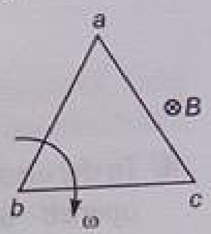
(d) if a proton is kept at $(-R, 0, 0)$ and magnetic field is increasing, then it will experience force in negative y-axis

9. In the figure shown, q is in coulomb and t in second. At time $t = 1$ s



(a) $V_a - V_b = 4$ V (b) $V_b - V_c = 1$ V (c) $V_c - V_d = 16$ V (d) $V_a - V_d = 20$ V

10. An equilateral triangular conducting frame is rotated with angular velocity ω in uniform magnetic field B as shown. Side of triangle is l. Choose the correct options.



(a) $V_a - V_c = 0$

(b) $V_a - V_c = \frac{B\omega l^2}{2}$

(c) $V_a - V_b = \frac{B\omega l^2}{2}$

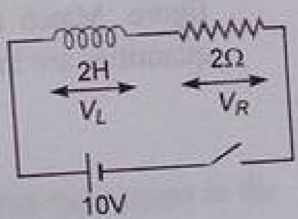
(d) $V_c - V_b = -\frac{B\omega l^2}{2}$

Match the Columns

1. Match the column.

Column I	Column II
(a) Magnetic induction	(p) $[MT^{-2}A^{-1}]$
(b) Coefficient of self induction	(q) $[L^2T^{-2}]$
(c) LC	(r) $[ML^2T^{-2}A^{-2}]$
(d) Magnetic flux	(s) None of these

2. In the circuit shown in figure, switch is closed at time $t = 0$. Match the following two columns.

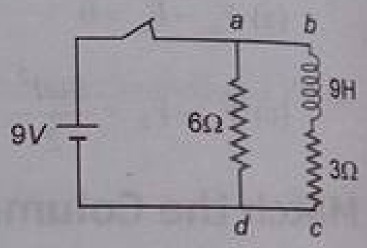


Column I	Column II
(a) V_L at $t = 0$	(p) zero
(b) V_R at $t = 0$	(q) 10 V
(c) V_L at $t = 1$ s	(r) $\frac{10}{e}$ V
(d) V_R at $t = 1$ s	(s) $\left(1 - \frac{1}{e}\right)$ 10 V

3. In an L-C oscillation circuit, $L = 1\,\text{H}$, $C = \frac{1}{4}\,\text{F}$ and maximum charge in capacitor is 4 C. Match the following two columns. Note that in column II all values are in SI units.

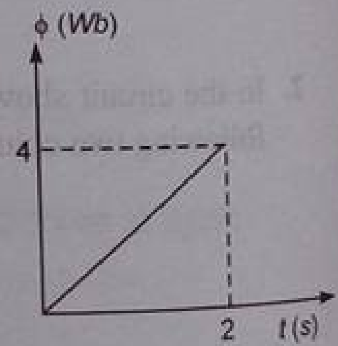
Column I	Column II
(a) Maximum current in the circuit	(p) 16
(b) Maximum rate of change of current in the circuit	(q) 4
(c) Potential difference across inductor when $q = 2C$	(r) 2
(d) Potential difference across capacitor when rate of change of current is half its maximum value	(s) 8

4. In the circuit shown in figure, switch remains closed for long time. It is opened at time $t = 0$. Match the following two columns at $t = (\ln 2)$ second.



Column I	Column II
(a) Potential differences across inductor	(p) 9 V
(b) Potential difference across $3\,\Omega$ resistance	(q) 4.5 V
(c) Potential difference across $6\,\Omega$ resistance	(r) 6 V
(d) Potential difference between points b and c	(s) None of these

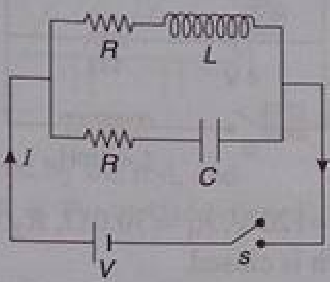
5. Magnetic flux passing through a coil of resistance $2\,\Omega$ is as shown in figure. Match the following two columns. In column II all physical quantities are in SI units.



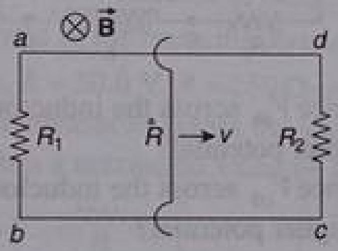
Column I	Column II
(a) Induced emf produced	(p) 4
(b) Induced current	(q) 1
(c) Charge flow in 2 s	(r) 8
(d) Heat generation in 2 s	(s) 2

Subjective Questions (Level 2)

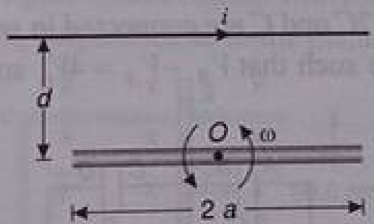
1. In the circuit diagram shown, initially there is no energy in the inductor and the capacitor. The switch is closed at $t = 0$. Find the current I as a function of time if $R = \sqrt{L/C}$.



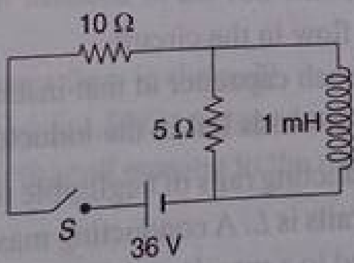
2. A rectangular loop with a sliding connector of length l is located in a uniform magnetic field perpendicular to the loop plane. The magnetic induction is equal to B. The connector has an electric resistance R, the sides ab and cd have resistances R_1 and R_2. Neglecting the self-inductance of the loop, find the current flowing in the connector during its motion with a constant velocity v.



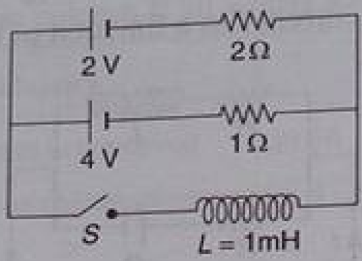
3. A rod of length $2a$ is free to rotate in a vertical plane, about a horizontal axis O passing through its midpoint. A long straight, horizontal wire is in the same plane and is carrying a constant current i as shown in figure. At initial moment of time, the rod is horizontal and starts to rotate with constant angular velocity ω, calculate emf induced in the rod as a function of time.



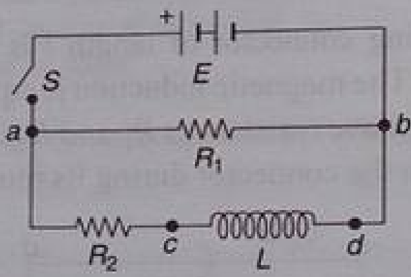
4. In the circuit arrangement shown in figure, the switch S is closed at $t = 0$. Find the current in the inductance as a function of time? Does the current through $10\,\Omega$ resistor vary with time or remains constant.



5. In the circuit shown, switch S is closed at time $t = 0$. Find the current through the inductor as a function of time t.



6. In the circuit shown in figure, $E = 120$ V, $R_1 = 30.0\,\Omega$, $R_2 = 50.0\,\Omega$, and $L = 0.200$ H. Switch S is closed at $t = 0$. Just after the switch is closed.

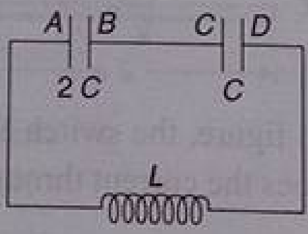


(a) What is the potential difference V_{ab} across the inductor R_1?
(b) Which point, a or b, is at higher potential?
(c) What is the potential difference V_{cd} across the inductor L?
(d) Which point, c or d, is at a higher potential?

The switch is left closed for a long time and then is opened. Just after the switch is opened

(e) What is the potential difference V_{ab} across the resistor R_1?
(f) Which point a or b, is at a higher potential?
(g) What is the potential difference V_{cd} across the inductor L?
(h) Which point, c or d, is at a higher potential?

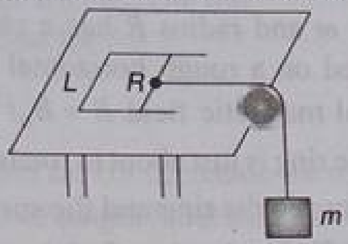
7. Two capacitors of capacitances $2C$ and C are connected in series with an inductor of inductance L. Initially capacitors have charge such that $V_B - V_A = 4V_0$ and $V_C - V_D = V_0$. Initial current in the circuit is zero. Find



(a) maximum current that will flow in the circuit,
(b) potential difference across each capacitor at that instant,
(c) equation of current flowing towards left in the inductor.

8. A pair of parallel horizontal conducting rails of negligible resistance shorted at one end is fixed on a table. The distance between the rails is L. A conducting massless rod of resistance R can slide on the rails frictionlessly. The rod is tied to a massless string which passes over a pulley fixed to the edge

of the table. A mass m tied to the other end of the string hangs vertically. A constant magnetic field B exists perpendicular to the table. If the system is released from rest. Calculate



(a) the terminal velocity achieved by the rod, and

(b) the acceleration of the mass at the instant when the velocity of the rod is half the terminal velocity.

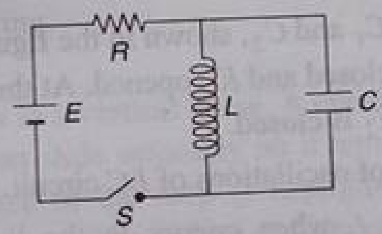
9. A 1.00 mH inductor and a 1.00 μF capacitor are connected in series. The current in the circuit is described by $i = 20\,t$, where t is in second and i is in ampere. The capacitor initially has no charge. Determine

(a) the voltage across the inductor as a function of time,

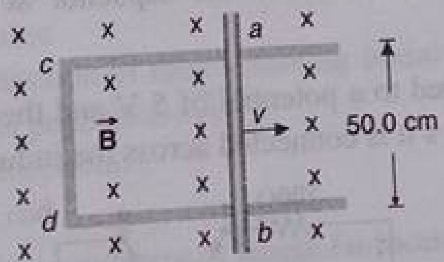
(b) the voltage across the capacitor as a function of time,

(c) the time when the energy stored in the capacitor first exceeds that in the inductor.

10. In the circuit shown in the figure, $E = 50.0$ V, $R = 250\,\Omega$ and $C = 0.500\,\mu$F. The switch S is closed for a long time, and no voltage is measured across the capacitor. After the switch is opened, the voltage across the capacitor reaches a maximum value of 150 V. What is the inductance L?



11. The conducting rod ab shown in figure makes contact with metal rails ca and db. The apparatus is in a uniform magnetic field 0.800 T, perpendicular to the plane of the figure.



(a) Find the magnitude of the emf induced in the rod when it is moving toward the right with a speed 7.50 m/s.

(b) In what direction does the current flow in the rod?

(c) If the resistance of the circuit $abdc$ is 1.50 Ω (assumed to be constant), find the force (magnitude and direction) required to keep the rod moving to the right with a constant speed of 7.50 m/s. You can ignore friction.

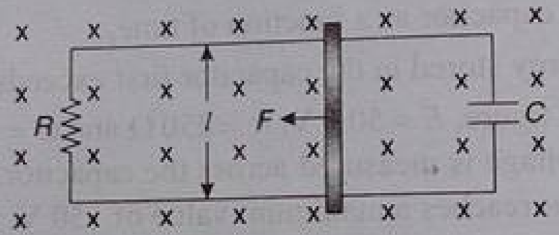
(d) Compare the rate at which mechanical work is done by the force (Fv) with the rate at which thermal energy is developed in the circuit (I^2R).

12. A non conducting ring of mass m and radius R has a charge Q unifromly distributed over its circumference. The ring is placed on a rough horizontal surface such that plane of the ring is parallel to the surface. A vertical magnetic field $B = B_0 t^2$ tesla is switched on. After 2 s from switching on the magnetic field the ring is just about to rotate about vertical axis through its centre.

(a) Find friction coefficient μ between the ring and the surface.

(b) If magnetic field is switched off after 4 s, then find the angle rotated by the ring before coming to stop after switching off the magnetic field.

13. Two parallel long smooth conducting rails separated by a distance l are connected by a movable conducting connector of mass m. Terminals of the rails are connected by the resistor R and the capacitor C as shown in figure. A uniform magnetic field B perpendicular to the plane of the rail is switched on. The connector is dragged by a constant force F. Find the speed of the connector as a function of time if the force F is applied at $t = 0$. Also find the terminal velocity of the connector.

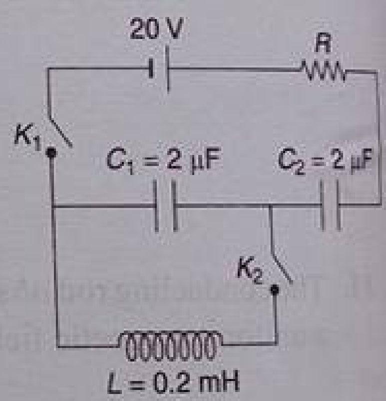


14. A circuit containing capacitors C_1 and C_2, shown in the figure is in the steady state with key K_1 closed and K_2 opened. At the instant $t = 0$, K_1 is opened and K_2 is closed.

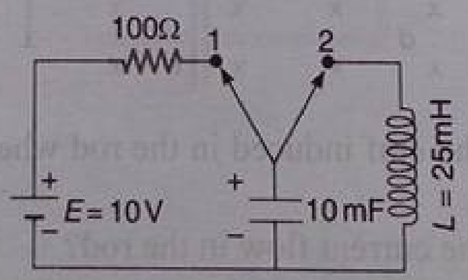
(a) Find the angular frequency of oscillations of LC circuit.

(b) Determine the first instant t, when energy in the inductor becomes one third of that in the capacitor.

(c) Calculate the charge on the plates of the capacitor at that instant.



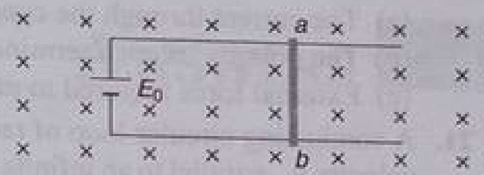
15. Initially the capacitor is charged to a potential of 5 V and then connected to position 1 with the shown polarity for 1 s. After 1 s it is connected across the inductor at position 2.



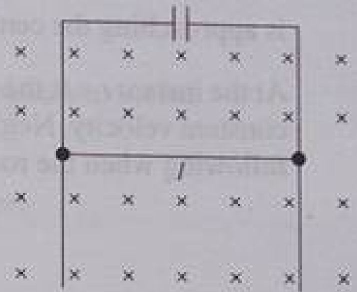
(a) Find the potential across the capacitor after 1 s of its connection to position 1.

(b) Find the maximum current flowing in the LC circuit when capacitor is connected across the inductor. Also find the frequency of LC oscillations.

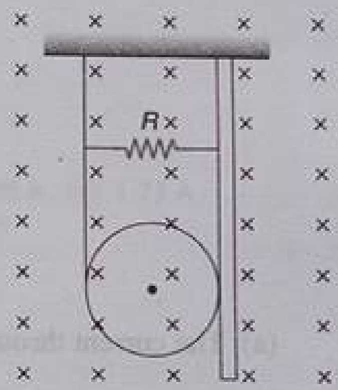
16. A rod of mass m and resistance R slides on frictionless and resistanceless rails a distance l apart that include a source of *emf* E_0. (see figure). The rod is initially at rest. Find the expression for the
(a) velocity of the rod $v(t)$.
(b) current in the loop $i(t)$.



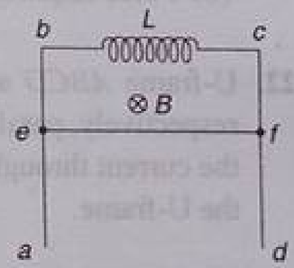
17. To metal bars are fixed vertically and are connected on the top by a capacitor C. A sliding conductor of length l and mass m slides with its ends in contact with the bars. The arrangement is placed in a uniform horizontal magnetic field directed normal to the plane of the figure. The conductor is released from rest. Find the displacement $x(t)$ of the conductor as a function of time t.



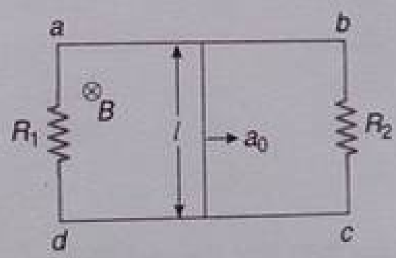
18. A conducting light string is wound on the rim of a metal ring of radius r and mass m. The free end of the string is fixed to the ceiling. A vertical infinite smooth conducting plane is always tangent to the ring as shown in the figure. A uniform magnetic field B is applied perpendicular to the plane of the ring. The ring is always inside the magnetic field. The plane and the string are connected by a resistance R. When the ring is released, find
(a) the current in the resistance R as a function of time.
(b) the terminal velocity of the ring.



19. A conducting frame $abcd$ is kept in a vertical plane. A conducting rod ef of mass m and length l can slide smoothly on it remaining always horizontal. The resistance of the loop is negligible and inductance is constant having value L. The rod is left from rest and allowed to fall under gravity and inductor has no initial current. A magnetic field of constant magnitude B is present throughout the loop pointing inwards. Determine
(a) position of the rod as a function of time assuming initial position of the rod to be $x = 0$ and vertically downward as the positive x-axis.
(b) the maximum current in the circuit.
(c) maximum velocity of the rod

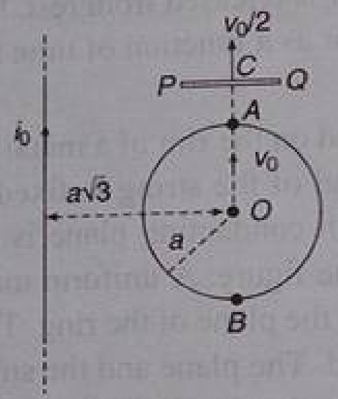


20. A rectangular loop with a sliding conductor of length l is located in a uniform magnetic field perpendicular to the plane of loop. The magnetic induction perpendicular to the plane of loop is equal to B. The part ad and bc has electric resistance R_1 and R_2 respectively. The conductor starts moving with constant acceleration a_0 at time $t = 0$. Neglecting the self inductance of the loop and resistance of conductor. Find



(a) The current through the conductor during its motion.
(b) The polarity of *abcd* terminal.
(c) External force required to move the conductor with the given acceleration.

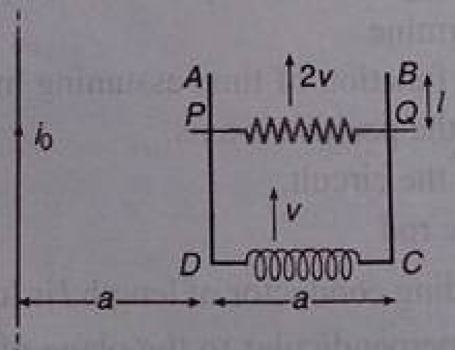
21. A conducting circular loop of radius a and resistance per unit length R is moving with a constant velocity v_0, parallel to an infinite conducting wire carrying current i_0. A conducting rod of length $2a$ is approaching the centre of the loop with a constant velocity $\frac{v_0}{2}$ along the direction of the current. At the instant $t = 0$, the rod comes in contact with the loop at A and starts sliding on the loop with the constant velocity. Neglecting the resistance of the rod and the self inductance of the circuit, find the following when the rod slides on the loop.



(a) The current through the rod when it is at a distance of $\left(\frac{a}{2}\right)$ from the point A of the loop.

(b) Force required to maintain the velocity of the rod at that instant.

22. U-frame $ABCD$ and a sliding rod PQ of resistance R, start moving with velocities v and $2v$ respectively, parallel to a long wire carrying current i_0. When the distance $AP = l$ at $t = 0$, determine the current through the inductor of inductance L just before connecting rod PQ loses contact with the U-frame.



ANSWERS

Introductory Exercise 24.1

1. Anticlockwise 2. No 3. $[ML^2A^{-1}T^{-3}]$

Introductory Exercise 24.2

1. Clockwise 2. Induced current in the loop is zero 3. Same direction, opposite direction.

Introductory Exercise 24.3

1. $e = aSB_0e^{-at}$ 2. No 3. 272 m 4. (a) $\frac{\mu_0 iv}{2\pi}\ln\left(1+\frac{l}{d}\right)$ (b) a (c) zero

Introductory Exercise 24.4

1. $3(t\cos t + \sin t)$

Introductory Exercise 24.5

1. (a) 4.5×10^{-5} H (b) 4.5×10^{-3} V 2. True

Introductory Exercise 24.7

1. (a) 6.3 V (b) 69 mH (c) 397 μs 3. (a) 4.00 A/s (b) 1.67 A/s (c) 0.639 A (d) 1.71 A
4. (a) $20.6(1-e^{-2.33t})$ W (b) $20.6(1-e^{-2.33t})^2$ W (c) $20.6(e^{-2.33t}-e^{-4.67t})$ W
(d) The expression in (a) is the sum of (b) and (c).
5. No 6. (a) $(0.5)(1-e^{-10t})A$ (b) $1.50\text{ A}-(0.25\text{ A})e^{-10t}$

Introductory Exercise 24.8

2. With KE as $v \Leftrightarrow i$ and $m \Leftrightarrow L$. Therefore, $\frac{1}{2}mv^2 = \frac{1}{2}Li^2$ 3. (a) 45.9 μC (b) 23.3 V 4. 20.0 V

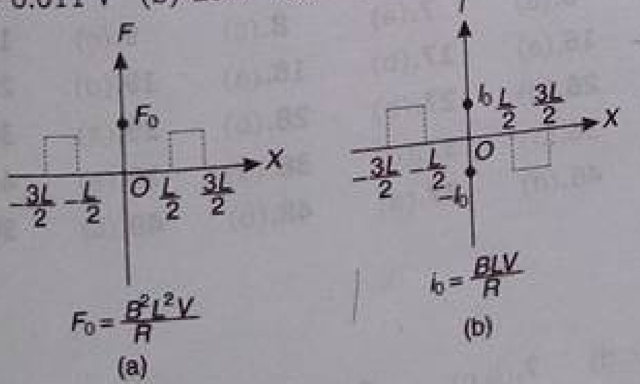
Introductory Exercise 24.9

1. (a) 3.1×10^{-6} V (b) 2.0×10^{-7} V/m
2. (a) 8.0×10^{-21} N (downward and to the right perpendicular to r_2)
(b) 0.36 V/m (upwards and to the left perpendicular to r_1)

AIEEE Corner

Subjective Questions (Level 1)

1. 6.74 V 2. 1600 μC 3. 0.5 T 4. 9.0×10^{-7} Wb 5. 4.4 V, north
6. (a) 0.011 V (b) zero (c) –0.011 V
7.



8. $e = \frac{\mu_0}{4\pi}\frac{2ia^2v}{x(x+a)}$ **9.** $(2\times10^{-5})\ln(10)$ V **10.** 0.00375 N **11.** 0.30 mA

12. (a) 1.62×10^{-2} V (b) a **13.** (a) 0.625 mH (b) 0.13 J, 0.21 J/s

14. 3.33×10^{-2} A, 6.67×10^{-2} A

15. (a) 0.250 H (b) 4.5×10^{-4} Wb **16.** 3.125 mH, 0.9375 V

17. (a) 2 H (b) 30 V (c) 1 H

18. (a) 0.27 V, Yes (b) 0.27 V **19.** (a) 1.96 H (b) 7.12×10^{-3} Wb

21. 0.37 **22.** (a) 0.2 s (b) 10 A (c) 9.93 A **23.** (a) 518 mW (b) 328 mW (c) 191 mW

24. (a) 2.40 A/s (b) 0.80 A/s (c) 0.413 A (d) 0.750 A

25. (a) 17.3 μs (b) 30.7 μs **26.** (a) $\frac{E}{r}e^{-\left(\frac{R+r}{L}\right)t}$ (b) $\frac{E^2L}{2r(R+r)}$ **27.** $\frac{8}{3}$ A

28. $12e^{-5t}$ volt, $6e^{-10t}$ A, clockwise **29.** $\frac{L_1}{L_2} = \frac{R_1}{R_2} = \frac{R_3}{R_4}$

30. (a) 3.6 mH (b) 1.33 kHz (c) 0.188 ms

31. (a) 6.28×10^3 rad/s, 10^{-3} s (b) $10^{-4}\cos(6.28\times10^3 t)$ (c) 0.0253 H (d) 0.4 A

32. (a) 1.25×10^{-2} V (b) 8.33×10^{-4} A (c) 3.125×10^{-8} J (d) 4.33×10^{-6} C, 7.8×10^{-7} J

33. (a) 10^4 A/s (b) zero (c) 2 A (d) 173 μC

34. (a) 6.5531 μJ (b) 0.0094 μJ (c) 6.5625 μJ

35. At a : $\left(\frac{qr}{2}\right)\left(\frac{dB}{dt}\right)$ towards left. At b : $\left(\frac{qr}{2}\right)\left(\frac{dB}{dt}\right)$ towards top of the page. At c : zero

36. (a) 1.7×10^{-4} V/m (b) 3.39×10^{-4} V/m

Objective Questions (Level 1)

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

JEE Corner

Assertion and Reason

1. (d)	2. (b)	3. (d)	4. (a,b)	5. (a)	6. (d)	7. (b)	8. (c)	9. (d)	10. (c)

Objective Questions (Level 2)

1.(b)	2.(c)	3.(a)	4.(b)	5.(c)	6.(a)	7.(a)	8.(c)	9.(c)	10.(a)
11.(b)	12.(b)	13.(c)	14.(a)	15.(b)	16.(a)	17.(b)	18.(a)	19.(d)	20.(a)
21.(a)	22.(d)	23.(a)	24.(b)	25.(b)	26.(d)	27.(b)	28.(b)	29.(a)	30.(c)
31.(c)	32.(b)	33.(b)	34.(c)	35.(a)	36.(a)	37.(d)	38.(d)	39.(a)	40.(b)
41.(c)	42.(b)	43.(a)	44.(c)	45.(a)	46.(d)	47.(a)	48.(b)	49.(c)	50.(c)
51.(a)	52.(d)								

More than One Correct Options

1.(a,c)	2.(a,c)	3.(a,c)	4.(a,b,d)	5.(a,d)	6.(b,c,d)	7.(b,c)	8.(b,c,d)	9.(a,b,c)	10.(a,c)

Match the Columns

1. (a) → p (b) → r (c) → s (d) → s
2. (a) → q (b) → p (c) → r (d) → s
3. (a) → s (b) → p (c) → s (d) → s
4. (a) → s (b) → q (c) → p (d) → p
5. (a) → s (b) → q (c) → s (d) → p

Subjective Questions (Level 2)

1. $I = \frac{V}{R}$ 2. $i = \frac{Bvl}{R + R'}$ where $R' = \frac{R_1 R_2}{R_1 + R_2}$ 3. $e = \frac{\mu_0 i\omega}{2\pi \sin \omega t}\left[\frac{d}{\sin \omega t} \ln\left(\frac{d - a\sin \omega t}{d + a \sin \omega t}\right) + 2a\right]$

4. $3.6\,(1 - e^{-t/\tau_L})$A. Here, $\tau_L = 300\,\mu s$. Current through $10\,\Omega$ resistor varies with time.

5. $i = 5(1 - e^{-2000t/3})$ A

6. (a) 120 V (b) a (c) 120 V (d) c (e) −72 V (f) b (g) −192 V (h) d

7. (a) $q_0\omega$ (b) $3V_0 : 3V_0$ (c) $i = q_0 \sin \omega t$. Here, $q_0 = 2CV_0$ and $\omega = \sqrt{\frac{3}{2LC}}$

8. (a) $\frac{mgR}{B^2L^2}$ (b) $\frac{g}{2}$ 9. (a) 20 mV (b) $10^7 t^2$ V (c) 63.2 μs 10. 0.28 H

11. (a) 3 V (b) b to a (c) 0.8 N (d) both are 6 W 12. (a) $\frac{2B_0QR}{mg}$ (b) $\frac{B_0Q}{m}$

13. $V = \frac{FR}{B^2l^2}(1 - e^{-\alpha t})$ Here, $\alpha = \frac{B^2l^2}{mR + RB^2l^2C}$, $v_T = \frac{FR}{B^2l^2}$

14. (a) 5×10^4 rad/s (b) 1.05×10^{-5} s (c) $10\sqrt{3}\,\mu$C 15. (a) 8.16 V (b) 5.16 A, 10 Hz

16. (a) $v = \frac{E_0}{Bl}(1 - e^{-\frac{B^2l^2}{mR}t})$ (b) $i = \frac{E_0 - Blv}{R}$ 17. $x = \frac{mgt^2}{2\,(m + CB^2l^2)}$

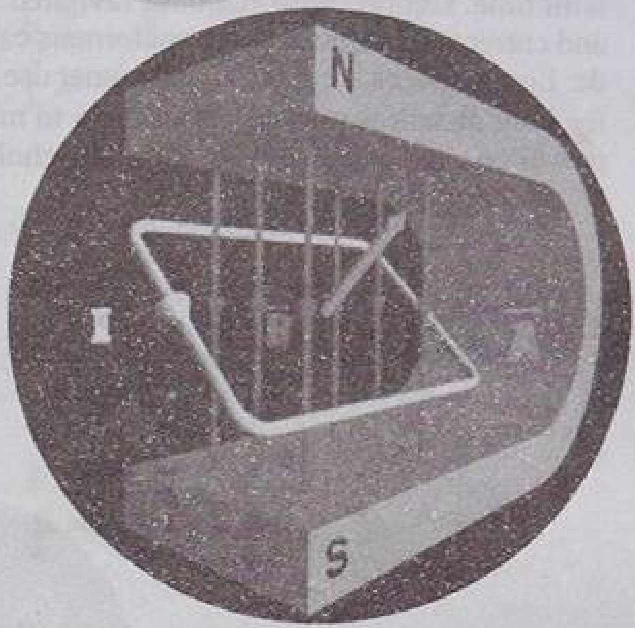
18. (a) $i = \frac{mg}{2Br}(1 - e^{-\frac{-2B^2r^2}{mR}t})$ (b) $v_T = \frac{mgR}{4B^2r^2}$

19. (a) $x = \frac{v_0}{\omega}(1 - \cos \omega t)$, $\omega = \frac{Bl}{\sqrt{mL}}$ (b) $i_{max} = \frac{2mg}{Bl}$ (c) $v_{max} = v_0 = \frac{g\sqrt{mL}}{Bl}$

20. (a) $i = \frac{Bla_0t}{R_1R_2}(R_1 + R_2)$ (b) Polarity of a, b is positive and polarity of c, d is negative

(c) $F_{ext} = a_0\left[m + \frac{B^2l^2t}{R_1R_2}(R_1 + R_2)\right]$

21. (a) $i = \frac{9v_0\mu_0 i_0}{16aR\pi^2}\ln(3)$ (b) $\frac{9\,\mu_0^2 i_0^2 v_0}{32aR\pi^3}(\ln 3)^2$ 22. $i = \left(\frac{e}{R}\right)[1 - e^{-lR/Lv}]$ where $e = \frac{\mu_0 i_0 v}{2\pi}\ln(2)$



25

Alternating Current

hapter Contents

Solved Examples

Example 1 *A sinusoidal voltage of frequency 60 Hz and peak value 150 V is applied to a series L-R circuit, where $R = 20\,\Omega$ and $L = 40$ mH.*

(a) Compute T, ω, X_L, Z and ϕ

(b) Compute the amplitudes of current, V_R and V_L

Solution (a)

$$T = \frac{1}{f} = \frac{1}{60}\ \text{s} \qquad \textbf{Ans.}$$

$$\omega = 2\pi f = 377\ \text{rad/s} \qquad \textbf{Ans.}$$

$$X_L = \omega L = (377)\,(0.040) = 15.08\,\Omega \qquad \textbf{Ans.}$$

$$Z = \sqrt{X_L^2 + R^2} = 25.05\,\Omega \qquad \textbf{Ans.}$$

$$\phi = \tan^{-1}\left(\frac{X_L}{R}\right) = \tan^{-1}(0.754)$$

$$= 37° \qquad \textbf{Ans.}$$

(b) Amplitudes (maximum value) are,

$$i_0 = \frac{V_0}{Z} = \frac{150}{25.05} \approx 6\text{A} \qquad \textbf{Ans.}$$

$$(V_0)_R = i_0 R = 120\ \text{V} \qquad \textbf{Ans.}$$

$$(V_0)_L = i_0 X_L = 90.5\ \text{V} \qquad \textbf{Ans.}$$

Note $V_0 = \sqrt{(V_0)_R^2 + (V_0)_L^2}$

Example 2 *For the circuit shown in figure, find the instantaneous current through each element.*

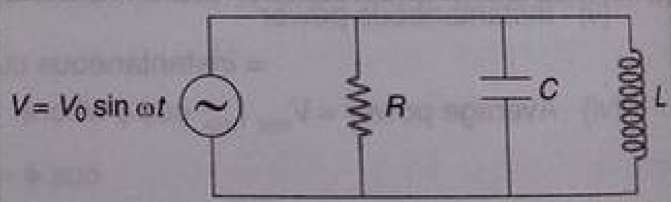


Fig. 25.26

Solution The three current equations are,

$$V = i_R R, \qquad V = L\frac{di_L}{dt}$$

and
$$\frac{dV}{dt} = \frac{1}{C} i_C \qquad \ldots\text{(i)}$$

The steady state solutions of Eq. (i) are,

$$i_R = \frac{V_0}{R}\sin\omega t = (i_0)_R \sin\omega t$$

$$i_L = -\frac{V_0}{\omega L}\cos\omega t = -\frac{V_0}{X_L}\cos\omega t = -(i_0)_L\cos\omega t$$

and $$i_C = V_0\omega C\cos\omega t = \frac{V_0}{X_C}\cos\omega t = (i_0)_C\cos\omega t$$

where, the reactances X_L and X_C are as defined.

Example 3 *In the above problem find the total instantaneous current through the source, and find expressions for phase angle of this current and the impedance of the circuit.*

Solution For the total current we have,

$$i = i_R + i_L + i_C$$

$$= V_0\left[\frac{1}{R}\sin\omega t + \left(\frac{1}{X_C} - \frac{1}{X_L}\right)\cos\omega t\right]$$

Using the trigonometric identity

$$A\sin\theta + B\cos\theta = \sqrt{A^2 + B^2}\sin(\theta + \phi)$$

where $\phi = \tan^{-1}(B/A)$

We can write, $$i = i_0\sin(\omega t + \phi)$$

Here, $$i_0 = \frac{V_0}{Z}$$

re, $$\frac{1}{Z} = \sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_C} - \frac{1}{X_L}\right)^2}$$

and $$\tan\phi = \frac{\left(\frac{1}{X_C} - \frac{1}{X_L}\right)}{(1/R)}$$

Example 4 *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) will get heated by 10°C.*

Solution The impedance of the circuit,

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{R^2 + \left\{(2\pi f L) - \frac{1}{(2\pi f C)}\right\}^2}$$

$$= \sqrt{(100)^2 + \left\{(2\times 3.14\times 750\times 0.1803) - \frac{1}{(2\times 3.14\times 750\times 10^{-5})}\right\}^2}$$

$$= 834\,\Omega$$

In case of an ac,

$$\langle P\rangle = V_{rms} i_{rms} \cos\phi = (V_{rms})\left(\frac{V_{rms}}{Z}\right)\left(\frac{R}{Z}\right) = \left(\frac{V_{rms}}{Z}\right)^2 R$$

$$= \left(\frac{20}{834}\right)^2 \times 100 = 0.0575 \text{ J/s}$$

Now, $\langle P\rangle \times t = S \cdot \Delta\theta$

Here, S = thermal capacity

$$\therefore \quad t = \frac{S \cdot \Delta\theta}{\langle P\rangle} = \frac{2\times 10}{0.0575} = 348 \text{ s} \qquad \textbf{Ans.}$$

Note *In ac the whole energy/power is consumed by resistance.*

Example 5 *An L-C-R series circuit with* $100\,\Omega$ *resistance is connected to an ac source of* $200\,V$ *and angular frequency* 300 *rad/s. When only the capacitance is removed, the current lags behind the voltage by* $60°$. *When only the inductance is removed, the current leads the voltage by* $60°$. *Calculate the current and the power dissipated in the L-C-R circuit.*

Solution When capacitance is removed,

$$\tan\phi = \frac{X_L}{R}$$

or

$$\tan 60° = \frac{X_L}{R}$$

$$\therefore \quad X_L = \sqrt{3}R \qquad \text{...(i)}$$

When inductance is removed,

$$\tan\phi = \frac{X_C}{R}$$

or

$$\tan 60° = \frac{X_C}{R}$$

$$\therefore \quad X_C = \sqrt{3}\,R \qquad \text{...(ii)}$$

From Eqs. (i) and (ii) we see that, $X_C = X_L$

So, the L-C-R circuit is in resonance.

Hence, $Z = R$

$$\therefore \quad i_{rms} = \frac{V_{rms}}{Z} = \frac{200}{100} = 2\text{A} \qquad \textbf{Ans.}$$

$$\langle P\rangle = V_{rms}\, i_{rms} \cos\phi$$

At resonance current and voltage are in phase, or $\phi = 0°$

$$\therefore \quad \langle P\rangle = (200)\,(2)\,(1) = 400 \text{ W} \qquad \textbf{Ans.}$$

Example 6 *A series L-C-R circuit containing a resistance of* $120\,\Omega$ *has angular frequency* 4×10^5 *rad/s. At resonance the voltages across resistance and inductance are* $60\,V$ *and* $40\,V$ *respectively. Find the values of L and C. At what angular frequency the current in the circuit lags the voltage by* $\pi/4$?

Solution At resonance, $X_L - X_C = 0$

and
$$Z = R = 120\,\Omega$$

$\therefore$
$$i_{rms} = \frac{(V_R)_{rms}}{R} = \frac{60}{120} = \frac{1}{2}\text{ A}$$

Also,
$$i_{rms} = \frac{(V_L)_{rms}}{\omega L}$$

$\therefore$
$$L = \frac{(V_L)_{rms}}{\omega i_{rms}} = \frac{40}{(4\times10^5)\left(\frac{1}{2}\right)}$$

$$= 2.0\times10^{-4}\text{ H} = 0.2\text{ mH}$$ **Ans.**

The resonance frequency is given by,

$$\omega = \frac{1}{\sqrt{LC}} \quad \text{or} \quad C = \frac{1}{\omega^2 L}$$

Substituting the values, we have

$$C = \frac{1}{(4\times10^5)^2\,(2.0\times10^{-4})}$$

$$= 3.125\times10^{-8}\text{ F}$$ **Ans.**

Current lags the voltage by 45°, when

$$\tan 45° = \frac{\omega L - \frac{1}{\omega C}}{R}$$

Substituting the values of L, C, R and tan 45°

we get,
$$\omega = 8\times10^5\text{ rad/s}$$ **Ans.**

Example 7 *A current of 4 A flows in a coil when connected to a* $12\,V$ *dc source. If the same coil is connected to a* $12\,V$, *50 rad/s ac source, a current of 2.4 A flows in the circuit. Determine the inductance of the coil. Also find the power developed in the circuit if a* $2500\,\mu F$ *capacitor is connected in series with the coil.*

Solution (i) A coil consists of an inductance (L) and a resistance (R).

In dc only resistance is effective. Hence,

$$R = \frac{V}{i} = \frac{12}{4} = 3\,\Omega$$

In ac, $$i_{rms} = \frac{V_{rms}}{Z} = \frac{V_{rms}}{\sqrt{R^2 + \omega^2 L^2}}$$

$\therefore$ $$L^2 = \frac{1}{\omega^2}\left[\left(\frac{V_{rms}}{i_{rms}}\right)^2 - R^2\right]$$

$\therefore$ $$L = \frac{1}{\omega}\sqrt{\left(\frac{V_{rms}}{i_{rms}}\right)^2 - R^2}$$

Substituting the values, we have

$$L = \frac{1}{50}\sqrt{\left(\frac{12}{2.4}\right)^2 - (3)^2} = 0.08 \text{ H}$$ **Ans.**

(ii) When capacitor is connected to the circuit, the impedance is,

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Here, $R = 3\,\Omega$

$$X_L = \omega L = (50)\,(0.08) = 4\,\Omega$$

and $$X_C = \frac{1}{\omega C} = \frac{1}{(50)\,(2500 \times 10^{-6})} = 8\,\Omega$$

$\therefore$ $$Z = \sqrt{(3)^2 + (4-8)^2} = 5\,\Omega$$

Now, $$\langle P \rangle = V_{rms} i_{rms} \cos\phi = V_{rms} \times \frac{V_{rms}}{Z} \times \frac{R}{Z}$$

$$= \left(\frac{V_{rms}}{Z}\right)^2 \times R$$

Substituting the values, we have $$\langle P \rangle = \left(\frac{12}{5}\right)^2 \times 3$$

$$= 17.28 \text{ W}$$ **Ans.**

Example 8 *A choke coil is needed to operate an arc lamp at* 160 *V (rms) and* 50 *Hz. The lamp has an effective resistance of* 5 Ω *when running at* 10 *A (rms). Calculate the inductance of the choke coil. If the same arc lamp is to be operated on* 160 *V (dc), what additional resistance is required? Compare the power loses in both cases.*

Solution For lamp,

$$(V_{rms})_R = (i_{rms})\,(R) = 10 \times 5 = 50 \text{ V}$$

In series,

$$(V_{rms})^2 = (V_{rms})_R^2 + (V_{rms})_L^2$$

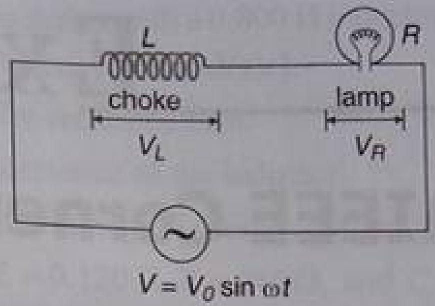


Fig. 25.27

$$\therefore \quad (V_{rms})_L = \sqrt{(V_{rms})^2 - (V_{rms})_R^2}$$

$$= \sqrt{(160)^2 - (50)^2}$$

$$= 152 \text{ V}$$

As $$(V_{rms})_L = (i_{rms}) X_L = (i_{rms})(2\pi f L)$$

$$\therefore \quad L = \frac{(V_{rms})_L}{(2\pi f)(i_{rms})}$$

Substituting the values $$L = \frac{152}{(2\pi)(50)(10)}$$

$$= 4.84 \times 10^{-2} \text{ H}$$ **Ans.**

Now, when the lamp is operated at 160 V dc and instead of choke let an additional resistance R' is put series with it then,

$$V = i(R + R')$$

$$160 = 10(5 + R')$$

$$\therefore \quad R' = 11 \Omega$$ **Ans.**

In case of ac, as the choke has no resistance, power loss in choke is zero.

In case of dc, the loss in additional resistance R' is,

$$P = i^2 R' = (10)^2 (11) = 1100 \text{ W}$$ **Ans.**

EXERCISES

AIEEE Corner

Subjective Questions (Level 1)

Note *You can take approximations in the answers.*

1. (a) What is the reactance of a 2.00 H inductor at a frequency of 50.0 Hz?
   (b) What is the inductance of an inductor whose reactance is 2.00 Ω at 50.0 Hz?
   (c) What is the reactance of a 2.00 μF capacitor at a frequency of 50.0 Hz?
   (d) What is the capacitance of a capacitor whose reactance is 2.00 Ω at 50.0 Hz?
2. A 300 Ω resistor, a 0.250 H inductor, and a 8.00 μF capacitor are in series with an ac source with voltage amplitude 120 V and angular frequency 400 rad/s.
   (a) What is the current amplitude?
   (b) What is the phase angle of the source voltage with respect to the current? Does the source voltage lag or lead the current?
   (c) What are the voltage amplitudes across the resistor, inductor, and capacitor?
3. In an L-C-R series circuit, $R = 150\,\Omega$, $L = 0.750$ H, and $C = 0.0180\,\mu$F. The source has voltage amplitude $V = 150$ V and a frequency equal to the resonance frequency of the circuit.
   (a) What is the power factor?
   (b) What is the average power delivered by the source?
   (c) The capacitor is replaced by one with $C = 0.0360\,\mu$F and the source frequency is adjusted to the new resonance value. Then, what is the average power delivered by the source?
4. A series circuit has an impedance of 60.0 Ω and a power factor of 0.720 at 50.0 Hz. The source voltage lags the current.
   (a) What circuit element, an inductor or a capacitor, should be placed in series with the circuit to raise its power factor?
   (b) What size element will raise the power factor to unity?
5. Voltage and current for a circuit with two elements in series are expressed as :

$$V(t) = 170 \sin(6280t + \pi/3) \text{ volt}$$
$$i(t) = 8.5 \sin(6280t + \pi/2) \text{ amp}$$

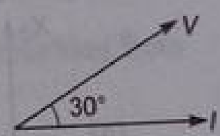
   (a) Plot the two waveforms.
   (b) Determine the frequency in Hz.
   (c) Determine the power factor stating its nature.
   (d) What are the values of the elements?
6. A 5.00 H inductor with negligible resistance is connected across an ac source. Voltage amplitude is kept constant at 60.0 V but whose frequency can be varied. Find the current amplitude when the angular frequency is
   (a) 100 rad/s, (b) 1000 rad/s (c) 10000 rad/s

7. A $300\,\Omega$ resistor is connected in series with a 0.800 H inductor. The voltage across the resistor as a function of time is $V_R = (2.50\text{ V})\cos[(950\text{ rad/s})t]$.
   (a) Derive an expression for the circuit current.
   (b) Determine the inductive reactance of the inductor.
   (c) Derive an expression for the voltage V_L across the inductor.
8. An *LCR* series circuit with $L = 0.120$ H, $R = 240\,\Omega$, and $C = 7.30\,\mu$F carries an rms current of 0.450 A with a frequency of 400 Hz.
   (a) What are the phase angle and power factor for this circuit?
   (b) What is the impedance of the circuit?
   (c) What is the rms voltage of the source?
   (d) What average power is delivered by the source?
   (e) What is the average rate at which electrical energy is converted to thermal energy in the resistor?
   (f) What is the average rate at which electrical energy is dissipated (converted to other forms) in the capacitor?
   (g) In the inductor?

Objective Questions (Level 1)

Single Correct Option

1. The term $\cos\phi$ in an AC circuit is called
   (a) form factor (b) phase factor (c) power factor (d) quality factor
2. A DC ammeter cannot measure alternating current because
   (a) AC changes its direction
   (b) DC instruments will measure the average value
   (c) AC can damage the DC instrument
   (d) AC produces more heat
3. As the frequency of an alternating current increases the impedance of the circuit
   (a) increases continuously (b) decreases continuously
   (c) remains constant (d) None of these
4. Phaser diagram of a series AC circuit is shown in figure. Then



   (a) The circuit must be containing resistor and capacitor only
   (b) The circuit must be containing resistor and inductor only
   (c) The circuit must be containing all three elements *L*, *C* and *R*
   (d) The circuit cannot have only capacitor and inductor
5. The rms value of an alternating current
   (a) is equal to 0.707 times peak value (b) is equal to 0.636 times peak value
   (c) is equal to $\sqrt{2}$ times the peak value (d) None of these
6. In an AC circuit the applied potential difference and the current flowing are given by :
   $V = 200\sin 100t$ volt, $I = 5\sin\left(100t - \frac{\pi}{2}\right)$ amp

The power consumption is equal to
(a) 1000 W (b) 40 W (c) 20 W (d) zero

7. The impedance of a series *LCR* circuit in an AC circuit is
(a) $\sqrt{R+(X_L-X_C)}$ (b) $\sqrt{R^2+(X_L^2-X_C^2)}$ (c) R (d) None of these

8. If V_0 and I_0 are the peak current and voltage across the resistor in a series *LCR* circuit, then the power dissipated in the circuit is
(a) $\frac{V_0 I_0}{2}$ (b) $\frac{V_0 I_0}{\sqrt{2}}$ (c) $V_0 I_0 \cos\varphi$ (d) $\frac{V_0 I_0}{2}\cos\varphi$

9. A generator produces a time varying voltage given by $V = 240 \sin 120\, t$, where t is in second. The rms voltage and frequency are
(a) 170 V and 19 Hz (b) 240 V and 60 Hz (c) 170 V and 60 Hz (d) 120 V and 19 Hz

10. An *LCR* series circuit has a maximum current of 5 A. If $L = 0.5$ H and $C = 8\,\mu$F, then the angular frequency of AC voltage is
(a) 500 rad/s (b) 5000 rad/s (c) 400 rad/s (d) 250 rad/s

11. The current and voltage functions in an AC circuit are

$$i = 100 \sin 100t \text{ mA}, \quad V = 100 \sin\left(100t + \frac{\pi}{3}\right) \text{V}$$

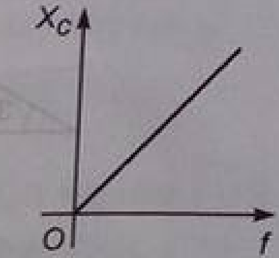
The power dissipated in the circuit is
(a) 10 W (b) 2.5 W (c) 5 W (d) 5 kW

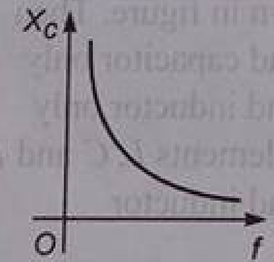
12. A capacitor becomes a perfect insulator for
(a) alternating current (b) direct current (c) both (a) and (b) (d) None of these

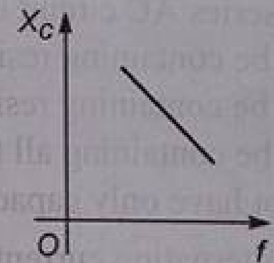
13. For an alternating voltage $V = 10 \cos 100\,\pi t$ volt, the instantaneous voltage at $t = \frac{1}{600}$ s is
(a) 1 V (b) 5 V (c) $5\sqrt{3}$ V (d) 10 V

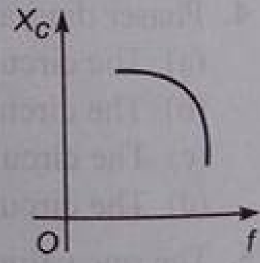
14. In a purely resistive AC circuit
(a) voltage leads current (b) voltage lags current
(c) voltage and current are in same phase (d) nothing can be said

15. Identify the graph which correctly represents the variation of capacitive reactance X_C with frequency

(a) 

(b) 

(c) 

(d) 

6. In an AC circuit, the impedance is $\sqrt{3}$ times the reactance, then the phase angle is
(a) 60° (b) 30° (c) zero (d) None of these

7. Voltage applied to an AC circuit and current flowing in it is given by :

$$V = 200\sqrt{2} \sin\left(\omega t + \frac{\pi}{4}\right) \text{and } i = -\sqrt{2} \cos\left(\omega t + \frac{\pi}{4}\right)$$

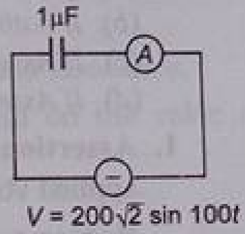
Then power consumed in the circuit will be

(a) 200 W (b) 400 W (c) $200\sqrt{2}$ W (d) None of these

18. When 100 volt DC source is applied across a coil, a current of 1 A flows through it. When 100 V AC source of 50 Hz is applied to the same coil, only 0.5 A current flows. Calculate the inductance of the coil

(a) $(\pi/\sqrt{3})$ H (b) $(\sqrt{3}/\pi)$ H (c) $(2/\pi)$ H (d) None of these

19. In the circuit shown in figure, the reading of the AC ammeter is



(a) $20\sqrt{2}$ mA
(b) $40\sqrt{2}$ mA
(c) 20 mA
(d) 40 mA

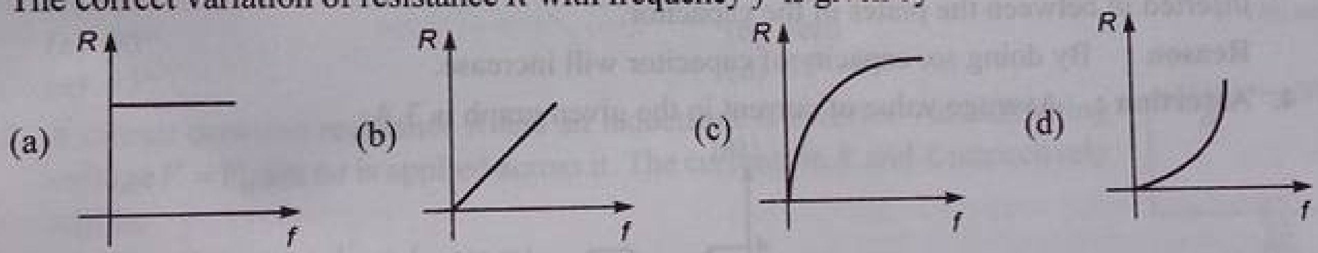
20. An AC voltage is applied across a series combination of L and R. If the voltage drop across the resistor and inductor are 20 V and 15 V respectively, then applied peak voltage is

(a) 25 V (b) 35 V (c) $25\sqrt{2}$ V (d) $5\sqrt{7}$ V

21. For wattless power in an AC circuit the phase angle between the current and voltage is

(a) 0° (b) 90° (c) 45° (d) Not possible

22. The correct variation of resistance R with frequency f is given by



23. If L and R be the inductance and resistance of the choke coil, then identify the correct statement.

(a) L is very high compared to R (b) R is very high compared to L
(c) Both L and R are high (d) Both L and R are low

24. When an AC signal of frequency 1 kHz is applied across a coil of resistance 100 Ω, then the applied voltage leads the current by 45°. The inductance of the coil is

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

25. The frequency of an alternating current is 50 Hz. The minimum time taken by it in reaching from zero to peak value is

(a) 5 ms (b) 10 ms (c) 20 ms (d) 50 ms

26. An alternating voltage is applied across the *R-L* combination. $V = 220 \sin 120t$ and the current $I = 4 \sin(120t - 60°)$ develops. The power consumption is

(a) zero (b) 100 W (c) 220 W (d) 440 W

JEE Corner

Assertion and Reason

Directions : *Choose the correct option.*

(a) *If both **Assertion** and **Reason** are true and the **Reason** is correct explanation of the **Assertion**.*
(b) *If both **Assertion** and **Reason** are true but **Reason** is not the correct explanation of **Assertion**.*
(c) *If **Assertion** is true, but the **Reason** is false.*
(d) *If **Assertion** is false but the **Reason** is true.*

1. **Assertion :** In an AC circuit potential difference across the inductor may be greater than the applied voltage.

   Reason : $V_C = IX_C$, whereas $V = IZ$ and X_C can be greater than Z also.

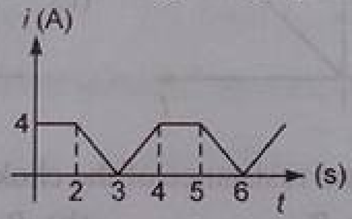
2. **Assertion :** In series LCR circuit, voltage will lead the current function for frequency greater than the resonance frequency.

   Reason : At resonance frequency, phase difference between current function and voltage function is zero.

3. **Assertion :** Resonance frequency will decrease in LCR series circuit if a dielectric slab is inserted in between the plates of the capacitor.

   Reason : By doing so, capacity of capacitor will increase.

4. **Assertion :** Average value of current in the given graph is 3 A.



   Reason : Average value can't be greater than the peak value of any function.

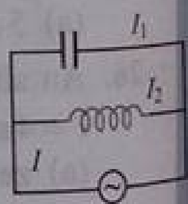
5. **Assertion :** In series LCR circuit if a ferromagnetic rod is inserted inside an inductor, current in the circuit may increase or decrease.

   Reason : By doing so V_L will increase.

6. **Assertion :** Potential difference across, resistor, capacitor and inductor each is 10 V. Then, voltage function and current functions should be in phase.

   Reason : At this condition current in the circuit should be maximum.

7. **Assertion :** At some given instant I_1 and I_2 both are 2 A each. Then I at this instant should be zero.



   Reason : There is a phase difference of π between I_1 and I_2 functions.

8. **Assertion :** Peak value of current in AC through a resistance of $10\,\Omega$ is 2 A. Then power consumed by the resistance should be 20 W.

   Reason : Power in AC is

$$P = I_{rms}^2 R$$

9. Assertion : An inductor coil normally produces more current with DC source compared to an AC source of same value of rms voltage.

Reason : In DC source applied voltage remains constant with time.

10. Assertion : In an L-R series circuit in AC, current in the circuit will decrease with increase in frequency.

Reason : Phase difference between current function and voltage function will increase with increase in frequency.

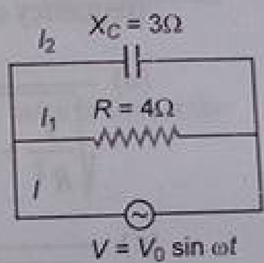
11. Assertion : In series LCR AC circuit, current and voltage are in same phase at resonance.

Reason : In series LCR AC circuit, resonant frequency does not depend on the value of resistance. Hence current, at resonance, does not depend on resistance.

Objective Questions (Level 2)

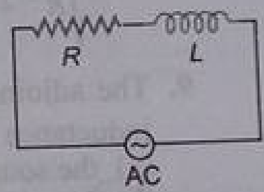
Single Correct Option

1. A capacitor and resistor are connected with an AC source as shown in figure. Reactance of capacitor is $X_C = 3\,\Omega$ and resistance of resistor is $4\,\Omega$. Phase difference between current I and I_1 is $\left[\tan^{-1}\left(\frac{3}{4}\right) = 37°\right]$



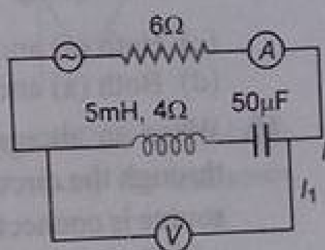
(a) 90° (b) zero
(c) 53° (d) 37°

2. A circuit contains resistance R and an inductance L in series. An alternating voltage $V = V_0 \sin \omega t$ is applied across it. The currents in R and L respectively will be



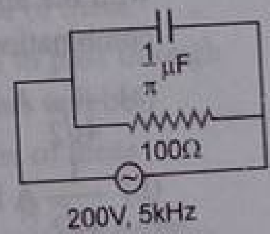
(a) $I_R = I_0 \cos \omega t$, $I_L = I_0 \cos \omega t$
(b) $I_R = -I_0 \sin \omega t$, $I_L = I_0 \cos \omega t$
(c) $I_R = I_0 \sin \omega t$, $I_L = -I_0 \cos \omega t$
(d) None of the above

3. In the circuit shown in figure, the AC source gives a voltage $V = 20 \cos(2000t)$. Neglecting source resistance, the voltmeter and ammeter readings will be



(a) 0 V, 2.0 A (b) 0 V, 1.4 A
(c) 5.6 V, 1.4 A (d) 8 V, 2.0 A

4. A signal generator supplies a sine wave of 200 V, 5 kHz to the circuit shown in the figure. Then choose the wrong statement

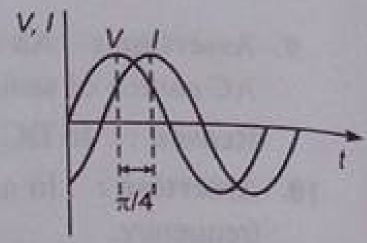


(a) The current in the resistive branch is 0.2 A
(b) The current in the capacitive branch is 0.126 A
(c) Total line current is ≈ 0.283 A
(d) Current in both the branches is same

5. A complex current wave is given by $i = (5 + 5 \sin 100\,\omega t)$ A. Its average value over one time period is given as

(a) 10 A (b) 5 A (c) $\sqrt{50}$ A (d) 0

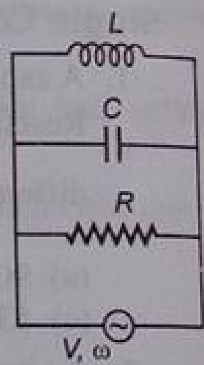
6. An AC voltage $V = V_0 \sin 100\,t$ is applied to the circuit, the phase difference between current and voltage is found to be $\pi/4$, then



(a) $R = 100\,\Omega; C = 1\,\mu F$
(b) $R = 1\,k\Omega; C = 10\,\mu F$
(c) $R = 10\,k\Omega; L = 1\,H$
(d) $R = 1\,k\Omega; L = 10\,H$

7. In series LCR circuit voltage drop across resistance is 8 V, across inductor is 6 V and across capacitor is 12 V. Then
(a) Voltage of the source will be leading in the circuit
(b) Voltage drop across each element will be less than the applied voltage
(c) Power factor of the circuit will be 3/4
(d) None of the above

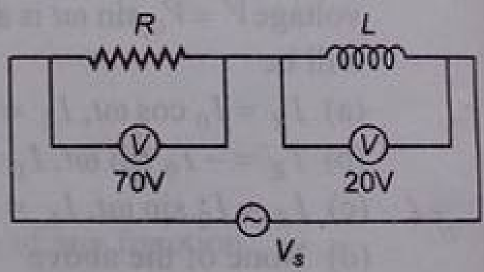
8. Consider an LCR circuit as shown in figure, with an AC source of peak value V_0 and angular frequency ω. Then the peak value of current through the AC source is



(a) $\dfrac{V_0}{\sqrt{\dfrac{1}{R^2} + \left(\omega L - \dfrac{1}{\omega C}\right)^2}}$ (b) $V_0\left[\dfrac{1}{R^2} + \left(\omega C - \dfrac{1}{\omega L}\right)\right]^2$

(c) $\dfrac{V_0}{\sqrt{R^2 + \left(\omega L - \dfrac{1}{\omega C}\right)^2}}$ (d) None of these

9. The adjoining figure shows an AC circuit with resistance R, inductance L and source voltage V_s. Then



(a) the source voltage $V_s = 72.8$ V
(b) the phase angle between current and source voltage is $\tan^{-1}(7/2)$
(c) Both (a) and (b) are correct
(d) Both (a) and (b) are wrong

10. When an alternating voltage of 220 V is applied across a device P, a current of 0.25 A flows through the circuit and it leads the applied voltage by an angle $\pi/2$ radian. When the same voltage source is connected across another device Q, the same current is observed in the circuit but in phase with the applied voltage. What is the current when the same source is connected across a series combination of P and Q?

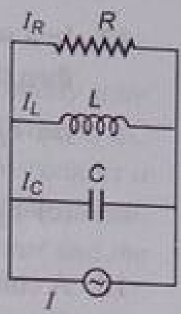
(a) $\dfrac{1}{4\sqrt{2}}$ A lagging in phase by $\pi/4$ with voltage

(b) $\dfrac{1}{4\sqrt{2}}$ A leading in phase by $\pi/4$ with voltage

(c) $\dfrac{1}{\sqrt{2}}$ A leading in phase by $\pi/4$ with voltage

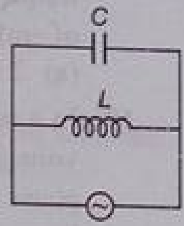
(d) $\dfrac{1}{4\sqrt{2}}$ A leading in phase by $\pi/2$ with voltage

11. In a parallel LCR circuit as shown in figure if I_R, I_L, I_C and I represents the rms values of current flowing through resistor, inductor, capacitor and the source, then choose the appropriate correct answer



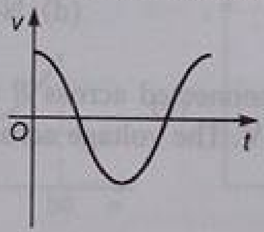
(a) $I = I_R + I_L + I_C$
(b) $I = I_R + I_L - I_C$
(c) I_L or I_C may be greater than I
(d) None of the above

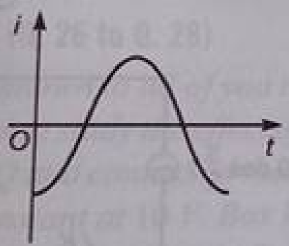
12. In the AC network shown in figure, the rms current flowing through the inductor and capacitor are 0.6 A and 0.8 A respectively. Then the current coming out of the source is

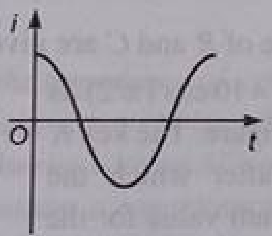


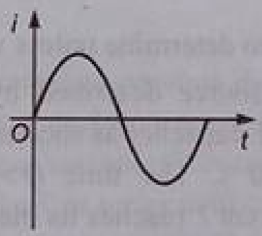
(a) 1.0 A
(b) 1.4 A
(c) 0.2 A
(d) None of the above

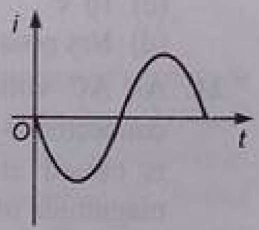
13. The figure represents the voltage applied across a pure inductor. The diagram which correctly represents the variation of current i with time t is given by



(a)


(b)


(c)


(d)


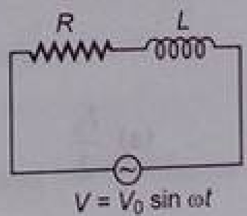
4. In a series LCR circuit, current in the circuit is 11 A when the applied voltage is 220 V. Voltage across the capacitor is 200 V. If value of resistor is $20\,\Omega$, then the voltage across the unknown inductor is

(a) zero (b) 200 V (c) 20 V (d) None of these

5. A steady current of magnitude I and an AC current of peak value I are allowed to pass through identical resistors for the same time. The ratio of heat produced in the two resistors will be

(a) 2 : 1 (b) 1 : 2 (c) 1 : 1 (d) None of these

. In the circuit shown in figure, the energy lost in one cycle is



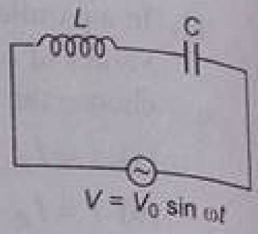
(a) zero

(b) $\dfrac{V_0^2}{2R}$

(c) $\dfrac{V_0^2 R}{2(R^2 + \omega^2 L^2)}$

(d) None of these

17. In a series LC circuit, the applied voltage is $V = V_0 \sin \omega t$. If ω is very low, then the voltage drop across the inductor V_L and capacitor V_C are



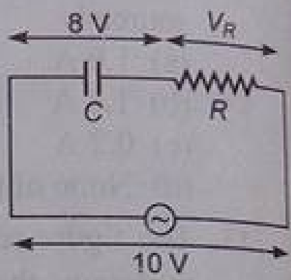
(a) $V_L = \frac{V_0}{2}; V_C = \frac{V_0}{2}$ (b) $V_L = 0; V_C = V_0$

(c) $V_L = V_0; V_C = 0$ (d) $V_L = -V_C = \frac{V_0}{2}$

18. A coil, a capacitor and an AC source of rms voltage 24 V are connected in series. By varying the frequency of the source, a maximum rms current of 6 A is observed. If coil is connected to a battery of emf 12 volt and internal resistance 4 Ω, then current through it in steady state is

(a) 2.4 A (b) 1.8 A (c) 1.5 A (d) 1.2 A

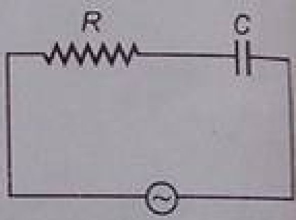
19. In a series CR circuit shown in figure, the applied voltage is 10 V and the voltage across capacitor is found to be 8 V. The voltage across R, and the phase difference between current and the applied voltage will respectively be



(a) 6 V, $\tan^{-1}\left(\frac{4}{3}\right)$ (b) 3 V, $\tan^{-1}\left(\frac{3}{4}\right)$

(c) 6 V, $\tan^{-1}\left(\frac{3}{4}\right)$ (d) None of these

20. A 50 Hz AC source of 20 V is connected across R and C as shown in figure. The voltage across R is 12 V. The voltage across C is



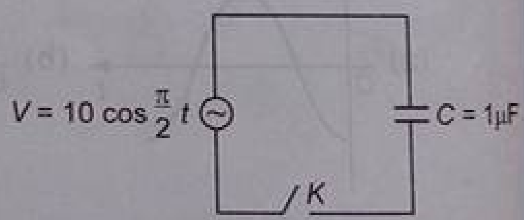
(a) 8 V

(b) 16 V

(c) 10 V

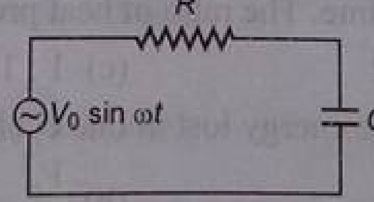
(d) Not possible to determine unless value of R and C are given

21. An AC voltage source described by $V = 10 \cos (\pi/2)$ is connected to a 1 μF capacitor as shown in figure. The key K is closed at $t = 0$ s. The time ($t > 0$) after which the magnitude of current I reaches its maximum value for the first time is



(a) 1 s (b) 2 s (c) 3 s (d) 4 s

22. An AC voltage source $V = V_0 \sin \omega t$ is connected across resistance R and capacitance C as shown in figure. It is given that $R = 1/\omega C$. The peak current is I_0. If the angular frequency of the voltage source is changed to $\omega/\sqrt{3}$ then the new peak current in the circuit is



(a) $\frac{I_0}{2}$ (b) $\frac{I_0}{\sqrt{2}}$ (c) $\frac{I_0}{\sqrt{3}}$ (d) $\frac{I_0}{3}$

Passage : (Q. 23 to Q. 25)

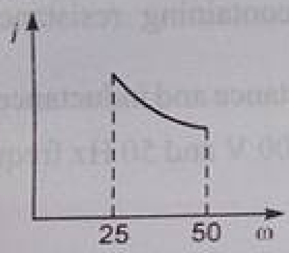
A student in a lab took a coil and connected it to a 12 V DC source. He measures the steady state current in the circuit to be 4 A. He then replaced the 12 V DC source by a 12 V, ($\omega = 50$ rad/s) AC source and observes that the reading in the AC ammeter is 2.4 A. He then decides to connect a 2500 μF capacitor in series with the coil and calculate the average power developed in the circuit. Further he also decides to study the variation in current in the circuit (with the capacitor and the battery in series).

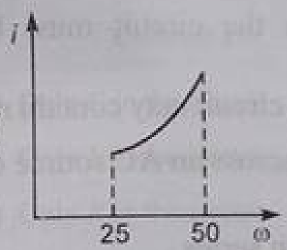
Based on the readings taken by the student answer the following questions.

23. The value of resistance of the coil calculated by the student is
(a) 3 Ω (b) 4 Ω (c) 5 Ω (d) 8 Ω

24. The power developed in the circuit when the capacitor of 2500 μF is connected in series with the coil is
(a) 28.8 W (b) 23.04 W (c) 17.28 W (d) 9.6 W

25. Which of the following graph roughly matches the variations of current in the circuit (with the coil and capacitor connected in the series) when the angular frequency is decreased from 50 rad/s to 25 rad/s

(a)


(b)


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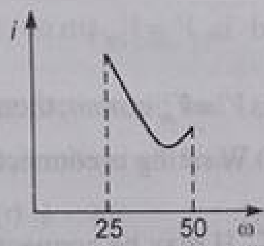

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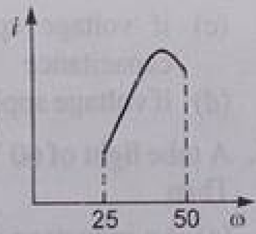


Passage : (Q. 26 to Q. 28)

It is known to all of you that the impedance of a circuit is dependent on the frequency of source. In order to study the effect of frequency on the impedance, a student in a lab took 2 impedance boxes P and Q and connected them in series with an AC source of variable frequency. The emf of the source is constant at 10 V. Box P contains a capacitance of 1 μF in series with a resistance of 32 Ω. And the box Q has a coil of self inductance 4.9 mH and a resistance of 68 Ω in series. He adjusted the frequency so that the maximum current flows in P and *Q. Based on his experimental set up and the reading by him at various moment answer the following questions.*

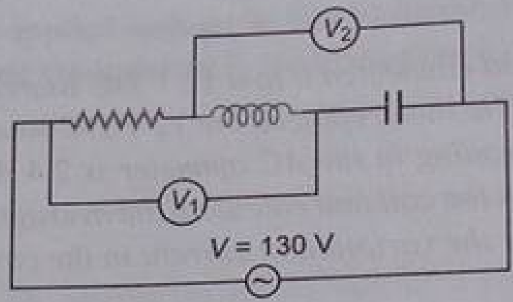
26. The angular frequency for which he detects maximum current in the circuit is
(a) $10^5/7$ rad/s (b) 10^4 rad/s (c) 10^5 rad/s (d) $10^4/7$ rad/s

27. Impedance of box *P* at the above frequency is
(a) 70 Ω (b) 77 Ω (c) 90 Ω (d) 100 Ω

28. Power factor of the circuit at maximum current is
(a) 1/2 (b) 1 (c) 0 (d) $1/\sqrt{2}$

More than One Correct Options

1. In a *R-L-C* series circuit shown, the readings of voltmeters V_1 and V_2 are 100 V and 120 V. Choose the correct statement(s).



(a) Voltage across resistor, inductor and capacitor are 50 V, 86.6 V and 206.6 V respectively
(b) Voltage across resistor, inductor and capacitor are 10 V, 90 V and 30 V respectively
(c) Power factor of the circuit is $\frac{5}{13}$
(d) Circuit is capacitive in nature

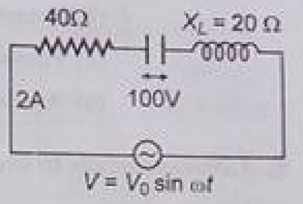
2. Current in an AC circuit is given by $i = 3\sin\omega t + 4\cos\omega t$ then
(a) rms value of current is 5 A
(b) mean value of this current in positive one-half period will be $\frac{6}{\pi}$
(c) if voltage applied is $V = V_m \sin\omega t$ then the circuit must be containing resistance an capacitance
(d) if voltage applied is $V = V_m \cos\omega t$, then the circuit may contain resistance and inductance onl

3. A tube light of 60 V, 60 W rating is connected across an AC source of 100 V and 50 Hz frequenc Then
(a) An inductance of $\frac{2}{5\pi}$ H may be connected in series
(b) A capacitor of $\frac{250}{\pi}$ μF may be connected in series to it
(c) An inductor of $\frac{4}{5\pi}$ H may be connected in series
(d) A resistance of 40 Ω may be connected in series

4. In an AC circuit, the power factor
(a) is unity when the circuit contains an ideal resistance only
(b) is unity when the circuit contains an ideal inductance only
(c) is zero when the circuit contains an ideal resistance only
(d) is zero when the circuit contains an ideal inductance only

5. In an AC series circuit given that, $R = 10\,\Omega$, $X_L = 20\,\Omega$ and $X_C = 10\,\Omega$. Then choose the cor options
(a) Voltage function will lead the current function
(b) Total impedance of the circuit is $10\sqrt{2}\,\Omega$
(c) Phase angle between voltage function and current function is 45°
(d) Power factor of circuit is $\frac{1}{\sqrt{2}}$

6. In the above problem further choose the correct options
   (a) The given values are at frequency less than the resonance frequency
   (b) The given values are at frequency more than the resonance frequency
   (c) If frequency is increased from the given value, impedence of the circuit will increase
   (d) If frequency is decreased from the given value, current in the circuit may increase or decrease
7. In the circuit shown in figure,
   (a) $V_R = 80$ V
   (b) $X_C = 50\,\Omega$
   (c) $V_L = 40$ V
   (d) $V_0 = 100$ V



8. In LCR series AC circuit
   (a) If R is increased current will decrease
   (b) If L is increased current will decrease
   (c) If C is increased current will increase
   (d) If C is increased current will decrease

Match the Columns

1. Match the following two columns for a series AC circuit.

Column I	Column II
(a) Only C in the circuit	(p) current will lead
(b) Only L in the circuit	(q) voltage will lead
(c) Only R in the circuit	(r) $\phi = 90°$
(d) R and C in the circuit	(s) $\phi = 0°$

2. Applied AC voltage is given as :

$$V = V_0 \sin \omega t$$

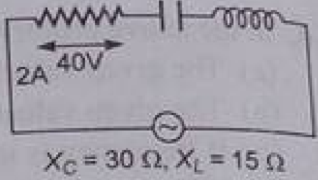
Corresponding to this voltage match the following two columns.

Column I	Column II
(a) $I = I_0 \sin \omega t$	(p) only R circuit
(b) $I = -I_0 \cos \omega t$	(q) only L circuit
(c) $I = I_0 \sin (\omega t + \pi/6)$	(r) may be C-R circuit
(d) $I = I_0 \sin (\omega t - \pi/6)$	(s) may be L-C-R circuit

3. For an LCR series AC circuit match the following two columns.

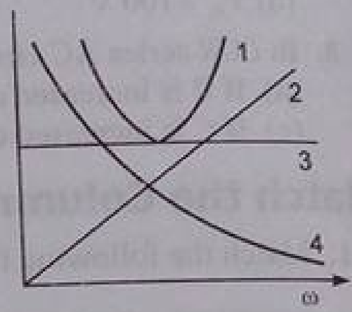
Column I	Column II
(a) If resistance is increased	(p) current will increase
(b) If capacitance is increased	(q) current will decrease
(c) If inductance is increased	(r) current may increase or decrease
(d) If frequency is increased	(s) power may decrease or increase

4. In the circuit shown in figure, match the following two columns. In column II quantities are given in SI units.



Column I	Column II
(a) Value of resistance R	(p) 60
(b) Potential difference across capacitor	(q) 20
(c) Potential difference across inductor	(r) 30
(d) Applied potential difference	(s) None of these

5. Corresponding to the figure shown, match the two columns.



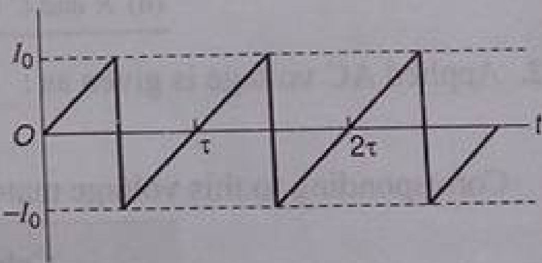
Column I	Column II
(a) Resistance	(p) 4
(b) Capacitive reactance	(q) 1
(c) Inductive reactance	(r) 2
(d) Impedence	(s) 3

Subjective Questions (Level 2)

Note Power factor leading means current is leading.

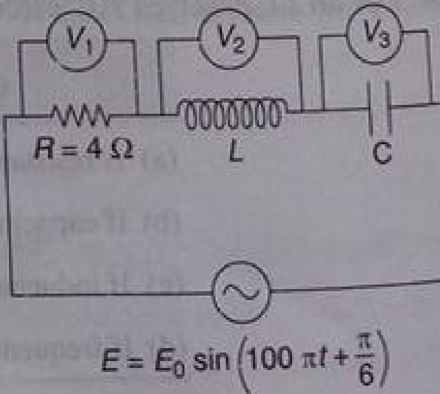
1. A coil is in series with a 20 μF capacitor across a 230 V, 50 Hz supply. The current taken by the circuit is 8 A and the power consumed is 200 W. Calculate the inductance of the coil if the current in the circuit is
   (a) leading, (b) lagging

2. The current in a certain circuit varies with time as shown in figure. Find the average current and the rms current in terms of I_0.

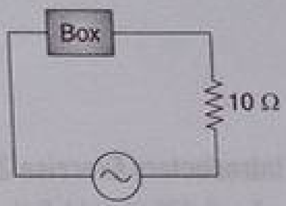


3. Two impedances Z_1 and Z_2 when connected separately across a 230 V, 50 Hz supply consume 100 W and 60 W at power factor of 0.5 lagging and 0.6 leading respectively. If these impedances are now connected in series across the same supply, find
   (a) total power absorbed and overall power factor
   (b) the value of reactance to be added in series so as to raise the overall power factor to unity.

4. In the figure shown the reading of voltmeters are $V_1 = 40$ V, $V_2 = 40$ V and $V_3 = 10$ V.
   Find
   (a) the peak value of current,
   (b) the peak value of emf,
   (c) the value of L and C.



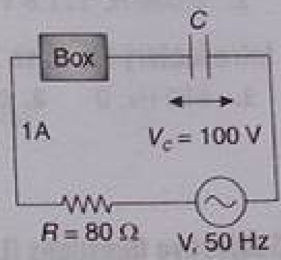
5. In the circuit shown in figure power factor of box is 0.5 and power factor of circuit is $\sqrt{3}/2$. Current leading the voltage. Find the effective resistance of the box.



6. A circuit element shown in the figure as a box is having either a capacitor or an inductor. The power factor of the circuit is 0.8, while current lags behind the voltage. Find

(a) the source voltage V,

(b) the nature of the element in box and find its value.



7. The maximum values of the alternating voltages and current are 400 V and 20 A respectively in a circuit connected to 50 Hz supply and these quantities are sinusoidal. The instantaneous values of the voltage and current are $200\sqrt{2}$ V and 10 A respectively. At $t = 0$ both are increasing positively.

(a) Write down the expression for voltage and current at time t.

(b) Determine the power consumed in the circuit.

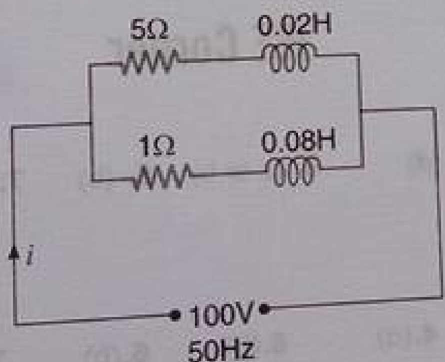
8. An LC circuit consists of an inductor coil with $L = 5.00$ mH and a 20.0 μF capacitor. There is negligible resistance in the circuit. The circuit is driven by a voltage source with $V = V_0 \cos \omega t$. If $V_0 = 5.00$ mV and the frequency is twice the resonance frequency, determine

(a) the maximum charge on the capacitor,

(b) the maximum current in the circuit,

(c) the phase relationships between the voltages across the inductor, the capacitor and the source.

9. A coil having a resistance of 5 Ω and an inductance of 0.02 H is arranged in parallel with another coil having a resistance of 1 Ω and an inductance of 0.08 H. Calculate the power absorbed when a voltage of 100 V at 50 Hz is applied.



10. A circuit takes a current of 3 A at a power factor of 0.6 lagging when connected to a 115 V – 50 Hz supply. Another circuit takes a current of 5A at a power factor of 0.707 leading when connected to the same supply. If the two circuits are connected in series across a 230 V, 50 Hz supply. Calculate

(a) the current (b) the power consumed and (c) the power factor.

ANSWERS

Introductory Exercise 25.1

1. 0.036 H, 111.8 V 2. 7.7 H, 6 A

Introductory Exercise 25.2

1. 650 Hz, 0 2. 0.2

AIEEE Corner

Subjective Questions (Level 1)

1. (a) 628 Ω (b) 6.37 mH (c) 1.59 kΩ (d) 1.59 mF
2. (a) 0.326 A (b) –35.3°, lagging (c) 97.9 V, 32.6 V, 102 V
3. (a) 1.00 (b) 75 W (c) 75 W 4. (a) Inductor (b) 0.133 H
5. (b) 1000 Hz (c) $\frac{\sqrt{3}}{2}$, leading (d) $R = 17.32\,\Omega, C = 15.92\,\mu F$
6. (a) 0.12 A (b) 1.2×10^{-2} A (c) 1.2×10^{-3} A
7. (a) (8.33 mA)cos (950 rad/s)t (b) 760 Ω (c) – (6.33 V) sin (950 rad/s)t
8. (a) +45.8°, 0.697 (b) 344 Ω (c) 155 V (d) 48.6 W (e) 48.6 W (f) 0 (g) 0

Objective Questions (Level 1)

1. (c) 2. (b) 3. (d) 4. (d) 5. (a) 6. (d) 7. (d) 8. (a) 9. (a) 10. (a)
11. (b) 12. (b) 13. (c) 14. (c) 15. (b) 16. (d) 17. (d) 18. (b) 19. (c) 20. (c)
21. (b) 22. (a) 23. (a) 24. (a) 25. (a) 26. (c)

JEE Corner

Assertion and Reason

1. (a) 2. (b) 3. (a) 4. (d) 5. (a or b) 6. (b) 7. (a) 8. (a,b) 9. (b) 10. (b)
11. (c)

Objective Questions (Level 2)

1.(c) 2.(d) 3.(c) 4.(d) 5.(b) 6.(b) 7.(d) 8.(b) 9.(a) 10.(b)
11.(c) 12.(c) 13.(c) 14.(b) 15.(a) 16.(c) 17.(b) 18.(c) 19.(a) 20.(b)
21.(a) 22.(b) 23.(a) 24.(c) 25.(b) 26.(a) 27.(b) 28.(b)

More than One Correct Options

1.(a,c,d) 2.(c,d) 3.(c,d) 4.(a,d) 5.(a,b,c,d) 6.(b,c,d) 7.(a,b,c) 8.(a)

Match the Columns

1. (a) → p,r (b) → q,r (c) → s (d) → p
2. (a) → p,s (b) → q (c) → r,s (d) → s
3. (a) → q,s (b) → r,s (c) → r,s (d) → r,s
4. (a) → q (b) → p (c) → r (d) → s
5. (a) → s (b) → p (c) → r (d) → q

Subjective Questions (Level 2)

1. (a) 0.416 H (b) 0.597 H **2.** zero, $\frac{I_0}{\sqrt{3}}$ **3.** (a) 99 W, 0.92 leading (b) 194.2 Ω

4. (a) $10\sqrt{2}$A (b) $50\sqrt{2}$V (c) $\frac{1}{25\pi}$H, (d) $\frac{1}{100\pi}$F **5.** 5 Ω

6. (a) 100 V (b) inductor, $L = \frac{1.6}{\pi}$H

7. (a) $V = 400 \sin(100\pi t + \pi/4)$, $i = 20 \sin(100\pi t + \pi/6)$ (b) $P = 3864$ W

8. (a) 33.4 nC (b) 0.211 mA
(c) Source and inductor voltages in phase. Capacitor voltage lags by 180°.

9. 797 W **10.** (a) 5.5 A (b) 1.188 kW (c) 0.939 lag

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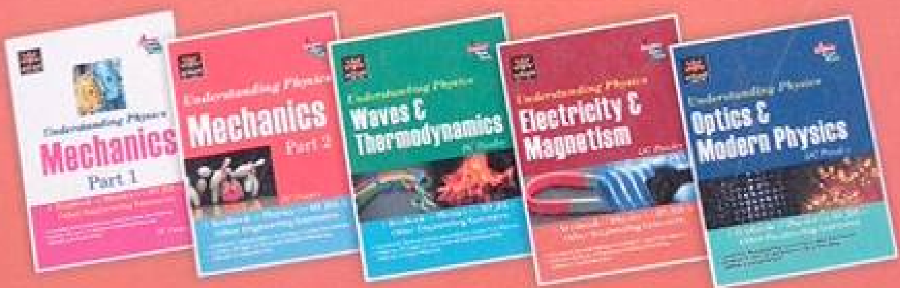

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