ELECTROMAGNETIC WAVES

1. DISPLACEMENT CURRENT

According to Ampere's circuital law, the line integral of the magnetic field ($\vec{B}$) around any closed path is equal to μ_0 times the net current across the area bounded by the path.

$$\oint_L \vec{B}.\vec{dl} = \;_0 I \qquad \ldots(i)$$

Where, I is the current flowing through the circumference of the surface enclosed by the closed path L.

James Clerk Maxwell suggested that a time varying electric field in vacuum produces a magnetic field, which is same as that produced by conduction current. This means that a changing electric field produces a current that flows through a region as long as the change in electric field lasts in that region. This current is called displacement current.

Thus, the displacement current is the current that comes into play in a region of time varying electric field or electric flux.

Mathematically,

$$I_D = \varepsilon_0 \frac{d\phi_E}{dt} \qquad \ldots(ii)$$

where, ϕ_E is the electric flux.

The concept of conduction and displacement current together leads to the modification in Ampere's circuital law, which can now be expressed as

$$\oint_L \vec{B}.\vec{dl} = \;_0(I + I_D)$$

Using equation (*ii*)

$$\oint_L \vec{B}.\vec{dl} = \mu_0(I + \varepsilon_0 \frac{d\phi_E}{dt}) \qquad \ldots(iii)$$

The equation (*iii*) represents the Ampere-Maxwell's law.

Maxwell's Equations

The four basic laws of electricity and magnetism, which predicts the existence of electromagnetic waves, are known as Maxwell's equations. They are:

(*i*) Gauss's law in electrostatics $\oint_S \vec{E}.\vec{ds} = \frac{q}{\varepsilon_0}$

(*ii*) Gauss's law in magnetism $\oint_S \vec{B}.\vec{ds} = 0$

(*iii*) Faraday's law of electromagnetic induction

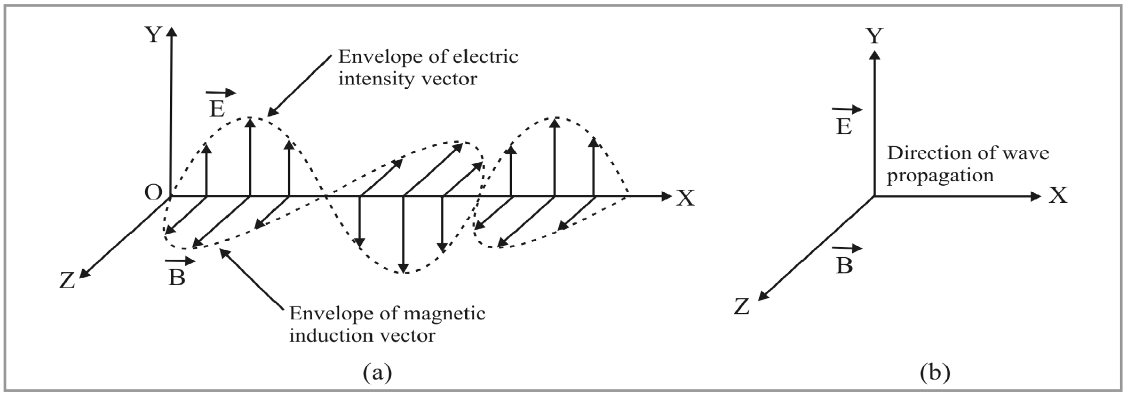
$$\oint \vec{E}.\vec{dl} = -\frac{d\phi_B}{dt}$$

(*iv*) Ampere-Maxwell's law

$$\oint \vec{B}.\vec{dl} = \mu_0 I + \mu_0\varepsilon_0 \frac{d\phi_E}{dt}$$

2. ELECTROMAGNETIC WAVES

Maxwell concluded that the variation of perpendicular electric and magnetic field vectors lead to the generation of certain electromagnetic disturbances in space.



3. ELECTROMAGNETIC WAVES

Maxwell concluded that the variation of perpendicular electric and magnetic field vectors lead to the generation of certain electromagnetic disturbances in space.

Properties of electromagnetic waves:

(*i*) Electromagnetic waves do not require any material medium for their propagation.

(*ii*) The direction of oscillation of electric and magnetic fields are perpendicular to each other as well as to the direction of propagation and the oscillations are sinusoidal.

(*iii*) Electromagnetic waves are transverse in nature.

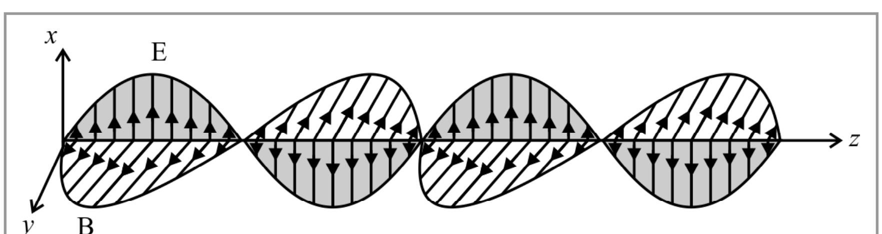
(*iv*) Electromagnetic waves travel with the speed of light (c) in free space, which is given by $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$

The relation between the wavelength λ, frequency ν and velocity c of an electromagnetic wave is given by:

$c = \nu\lambda$

Hertz realized that the electromagnetic waves in the metre to millimetre range could be produced in the laboratory using oscillating dipole antennas. The SI unit of frequency is named hertz (Hz) to honour him.

(*v*) In Figure, we show a typical example of a plane electromagnetic wave propagating along the z direction (the fields are shown as a function of the z coordinate, at a given time t). The electric field E_x is along the x-axis, and varies sinusoidally with z, at a given time. The magnetic field By is along the y-axis, and again varies sinusoidally with z. The electric and magnetic fields E_x and By are perpendicular to each other, and to the direction z of propagation. We can write Ex and By as follows:



A linearly polarised electromagnetic wave, propagating in the *z*-direction with the oscillating electric field **E** along the *x*-direction and the oscillating magnetic field **B** along the *y*-direction.

$E_x = E_0 \sin(kz - \omega t)$ ....(*i*), $B_y = B_0 \sin(kz - \omega t)$ ....(*ii*)

Here k is related to the wave length λ of the wave by the usual equation

$k = \frac{2\pi}{\lambda}$ ....(*iii*) and ω is the angular frequency. k is the magnitude of the wave vector (or propagation vector) k and its direction describes the direction of propagation of the wave. The speed of propagation of the wave is (ω/k). Using Eqs. [(*i*) and (*ii*)] for E_x and B_y and Maxwell´s equations, one finds that

$$\omega = ck, \text{ where, } c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} \qquad ....(iv)$$

The relation ω = ck is the standard one for waves. This relation is often written in terms of frequency, $v = (\omega / 2\pi)$ and wavelength, $v = (\omega / 2\pi)$ as

It is also seen from Maxwell's equations that the magnitude of the electric and the magnetic fields in an electromagnetic wave are related as $B_0 = (E_0/c)$ ....(*v*)

4. ELECTROMAGNETIC SPECTRUM

The systematic distribution of electromagnetic radiations into groups as per their wavelength or frequency is referred to as the electromagnetic spectrum.

- Electromagnetic waves cover a wide range of frequencies (or wavelengths).
- Classification is done according to the main source of electromagnetic waves.
- Various sources may produce waves in overlapping ranges of frequencies. Therefore, classification does not have sharp and well-defined boundaries.
- The physical properties of electromagnetic waves are decided by their wavelengths.

  The entire electromagnetic spectrum can be summarised as below.

Frequency Range(Hz)	Components of electromagnetic spectrum	Wavelength Range(m)	Sources
5×10^{22} to 3×10^{19}	Gamma Rays	6×10^{-14} to 1×10^{-11}	Nuclear origin
3×10^{19} to 1×10^{16}	X-rays	1×10^{-11} to 3×10^{-8}	Sudden deceleration of high energy electron
5×10^{17} to 8×10^{14}	Ultra violet	6×10^{-10} to 4×10^{-7}	Excitation of atom, spark and arc lamp
8×10^{14} to 4×10^{14}	Visible light	4×10^{-7} to 8×10^{-7}	Excitation of valence electron
4×10^{14} to 1×10^{13}	Infrared	8×10^{-7} to 3×10^{-5}	Excitation of atoms and molecules
3×10^{11} to 1×10^{9}	Microwaves	10^{-3} to 0.3	Oscillating current in special vacuum tubes
3×10^{9} to 3×10^{8}	Ultra High Frequencies	1×10^{-1} to 1	Oscillating circuit
3×10^{8} to 3×10^{7}	Very High Radio Frequenices	1 to 10	Oscillating circuit
3×10^{7} to 3×10^{4}	Radio Frequencies	10 to 10^{6}	Oscillating circuit
60 to 50	Power frequencies	5×10^{6} to 6×10^{6}	Weak radiation from ac circuit

- Only a small portion of the spectrum is visible to the human eye.

Main Components of The Electromagnetic Spectrum

Gamma Rays

- Are highly energetic radiations emitted by radioactive substances.
- Are of nuclear origin.
- Help in studying the structure of atomic nuclei.
- When absorbed by living organisms, gamma rays can produce adverse effects.
- Heavy shielding and extreme precautions are required in the handling of gamma rays.

X-rays
- Discovered by W C Roentgen.
- Is of atomic origin
- Produced when a target of an element with high atomic number is bombarded with fast moving electrons.
- Used in medical diagnosis and for the treatment of cancer.
- Used for detection of opium, silver, gold and explosives in the body of the smugglers
- Used to detect flaws like cracks and holes in metal products
- Used in testing of welding, casting and moulding.

Ultraviolet Rays (UV Rays)
- Part of the solar spectrum.
- Wavelength is less compared to the visible light.
- Can be produced by arcs of mercury and iron.
- Used in medical applications, sterilisation processes and preservation of foodstuff.
- Used in burglar alarms and in the forensic laboratory (in detecting fingerprints and in the detection of forged documents).

Visible Light
- Human eye is sensitive only to the visible spectrum.
- Forms only a narrow part of the electromagnetic spectrum
- Emitted due to atomic excitation.
- Constituent colours: Violet, indigo, blue, green, yellow, orange and red (VIBGYOR)

Infrared Rays
- Wavelength is more compared to the visible light.
- Responsible for the heating effect.
- About 60% of the solar radiations are infrared in nature.
- Weather forecasting is done through infrared photography.
- Used in solar water heaters and solar cookers.

Microwaves
- Produced by special vacuum tubes (klystrons, magnetrons and Gunn diodes).
- Used in radar and other communication systems.
- Used in molecular study.
- Used in microwave ovens to heat the food stuff.

Radio Waves
- Produced by accelerated motion of charges in conducting wires.
- Also generated by oscillating electronic circuits.
- Used as carrier waves in radio broadcasting and television transmission.
- Used in cell phones.

2011

1. A plane electromagnetic wave travels in vacuum along y-direction. What can you say about the direction of electric and magnetic field vectors? **(1 marks)**

2. How are infrared waves produced? Why are these refered to as 'heat waves' ? Write their one important use. **(2 marks)**

2010

1. Which part of electromagnetic spectrum is used in radar systems? **(1 Mark)**

2. What is the range of frequencies used in satellite communication? What is common between these waves and light waves? **(2 Mark)**

2009

1. Name the electromagnetic radiation to which waves of wavelength in the range of 10^{-2} m belong. Give one use of this part of EM spectrum. **(1 Mark)**

2. Name the part of electromagnetic spectrum which is suitable for
(*i*) radar systems used in aircraft navigation (*ii*) treatment of cancer tumours. **(1 Mark)**

3. How does a charge q oscillating at certain frequency produce electromagnetic waves.
Sketch a schematic diagram depicting electric and magnetic fields for an electromagnetic wave propagating along the Z-direction **(2 Marks)**

2008

1. Name the part of the electromagnetic spectrum of wavelength 10^2 m and mentionone of its applications. **(1 Mark)**

2. The oscillating magnetic field in a plane electromagnetic wave is given by **(2 Marks)**

$$\vec{B} = (8 \times 10^{-6}) \sin[(2 \times 10^{11})t + 300\pi x] \text{ T}$$

(*i*) Calculate the wavelength of the electromagnetic wave.
(*ii*) Write down the expression for the oscillating electric field.

2007

1. Write any four characteristics of electromagnetic waves. Give two uses each of **(3 Marks)**
(*i*) Radio-waves (*ii*) Microwaves.

2. Name the following constituent radiations of electromagnetic spectrum **(3 Marks)**
(*i*) Which produce intense heating effect.
(*ii*) Is absorbed by the ozone layer in the atmosphere.
(*iii*) Is used for studying crystal structure.
Write one application for each of these radiations.

2006

1. Name the electromagnetic radiation to which the following wavelengths belong: (*a*) 10^{-3}m (*b*) 1 A **(1 Mark)**

2. A plane electromagnetic wave of frequency 25 MHz travels in free space along the *x*-direction.
At a particular point in space and time the electric vector is $\vec{E} = 6.3\,\hat{j}\ \text{Vm}^{-1}$. Calculate $\vec{B}$ at this point. **(2 Marks)**

3. Write the order of frequency range and one use of each of the following electromagnetic radiations. **(3 Marks)**
(*i*) Microwaves (*ii*) Ultraviolet rays (*iii*) Gamma rays

4. Draw a labelled diagram of Hertz's experimental set-up to produce electromagnetic waves. Explain the generation of electromagnetic waves using this set-up. **(3 Marks)**

2005

1. Give reasons for the following: **(3 Marks)**
(*i*) Long distance radio broadcasts use short-wave bands.
(*ii*) The small ozone layer on top of the stratosphere is crucial for human survival.
(*iii*) Satellites are used for long distance TV transmission.

2. Name the constituent radiation of electromagnetic spectrum which **(3 Marks)**

(*a*) is used in satellite communication. (*b*) is used for studying crystal structure.

(*c*) is similar to the radiations emitted during decay of radioactive nuclei.

(*d*) has its wavelength range between 390 nm and 770 nm. (*e*) is absorbed from sunlight by ozone layer.

(*f*) produces intense heating effect.

3. Write two applications of each (*i*) microwaves, (*ii*) infra red waves, (*iii*) radio waves. **(3 Marks)**

4. Name the radiations of electromagnetic spectrum which are used in **(3 Marks)**

(*a*) warfare to look through fog. (*b*) radar and geostationary satellites.

(*c*) studying the structure and properties of atoms and molecules.

PRACTICE QUESTIONS

1. The small ozone layer on top of the stratosphere is crucial for human survival. Why.

2. Some scientists have predicted that a global nuclear war on the earth would be followed by a severe 'nuclear winter' with a devastating effect on life on earth. What might be the basis of this prediction.

3. What oscillates in electromagnetic waves. Are these waves transverse or longitudinal.

4. Write the relationship between amplitudes of electric and magnetic fields in free space for an electromagnetic wave.

5. What feature of electromagnetic waves led Maxwell to conclude that light itself is electromagnetic wave.

6. What evidence is there that sound is not electromagnetic in nature.

7. What is the range of wavelengths of electromagnetic waves produced by J.C. Bose.

8. Which of the following has the shortest: wavelength, microwaves, ultraviolet rays and X-rays.

9. Write the following radiations in an ascending order in respect of their frequencies: Infrared rays, radio waves, γ -rays.

10. Rewrite the following radiations in a descending order of wavelength values:
Infrared rays, radio waves, γ -rays and microwaves.

11. What is the ratio of speed of infrared rays and ultraviolet rays in vacuum.

12. Write the frequency limit of visible range of electromagnetic spectrum in kHz.

13. Name the electromagnetic radiation to which the following wavelengths belong:(*a*) 10^{-2} m (*b*) 1Å

14. What is the ratio of speed of gamma rays and radiowaves in vacuum.

15. Is the ratio of frequencies of ultraviolet rays and infrared rays in glass more than, less than or equal to 1.

16. Which of the following has the lowest frequency: microwaves, ultraviolet rays and X-rays.

17. Which of the following has the shortest wavelength: microwaves, ultraviolet rays and X-rays.

18. Which part of the electromagnetic spectrum is used in operating a Radar.

Or

What is the name given to that part of electromagnetic spectrum which is used in Radar.

19. Why are microwaves used in radar.

20. Name the electromagnetic radiations used for viewing objects through haze and fog.

21. Which part of the electromagnetic spectrum has the largest pentarating power.

22. How does the frequency of a beam of ultraviolet light change when it goes from air into glass.

23. What is the name given to that part of electromagnetic spectrum which is used for taking photographs of earth under foggy conditions from great heights.

24. Name the type of radio wave propagation involved when TV signals, broadcast by a tall antenna, are intercepted directly by the receiver antenna.

25. Name the electromagnetic waves that have frequencies greater than those of ultraviolet light but less than those of γ -rays.

26. What is the nature of waves used in radar. What is their wavelength range.

27. Name the electromagnetic radiations used for studying crystal structure of solids.

28. What is the ratio of speed of γ -rays and radio waves in vacuum.

29. Which part of electromagnetic spectrum has highest frequency.

30. In a plane electromagnetic wave the electric field oscillates sinusoidally with a frequency of 2×10^{10} Hz and amplitude 48 Vm^{-1}. What is the wavelength of the wave.

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