# ELECTROMAGNETIC WAVES

# *ELECTROMAGNETIC WAVES*

**MARKS WEIGHTAGE – 3 marks**

## ***QUICK REVISION (Important Concepts & Formulas)***

- **Electromagnetic radiation** is the radiation in which associated electric and magnetic field oscillations are propagated through space. The electric and magnetic fields are at right angle to each other and to the direction of propagation.
- Propagation of electromagnetic wave through space is fully described in terms of wave theory but interaction with matter depends on quantum theory.
- Maxwell showed that the changing electric field intensity is equivalent to a current through the capacitor. This current through the capacitor is known as displacement current.

$$I_d = \frac{\varepsilon_0 d\phi_E}{dt}$$

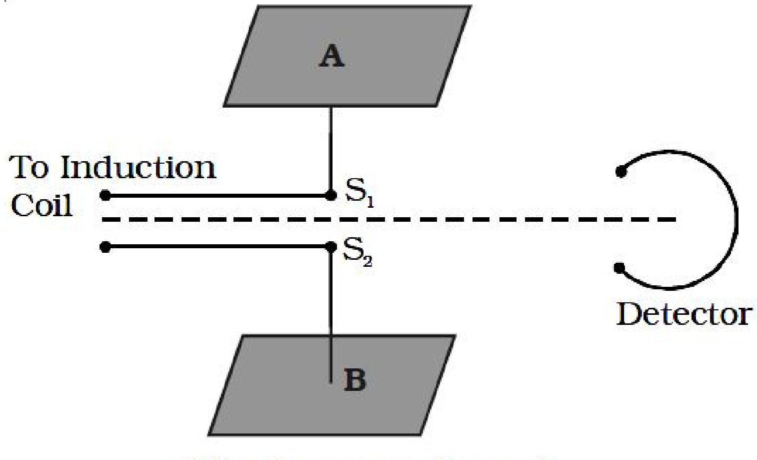
- Maxwell was first to provide the mathematical structure of the laws of electromagnetism.
- The basic principle of electromagnetism can be formulated in terms of four fundamental equations called Maxwell's equations.
- Four Maxwell's equations are –
- Gauss's law for electrostatics

  $\oiint \vec{E}.d\vec{S} = \frac{q}{\varepsilon_0}$ which describes the charge and the electric field.
- Gauss's law for magnetism

  $\oiint \vec{B}.d\vec{S} = 0$ which describes the magnetic field.
- Faraday's law of induction

  $\oint \vec{E}.d\vec{l} = -\frac{d\phi_B}{dt}$ which describes the electrical effect of a changing magnetic field.
- Ampere's law of induction (as extended by Maxwell)

  $\oint \vec{B}.d\vec{l} = \mu_0 i + \mu_0\varepsilon_0 \frac{d\phi_E}{dt}$ which describes the magnetic effect of a current or a changing electric field.
- Maxwell's equations apply to electric and magnetic fields in vacuum. They may also be generalised to include fields in matter.
- Hertz was first to demonstrate the production of electromagnetic waves in the laboratory which is based on principle that a vibrating charge radiates electromagnetic waves.
- Hertz produced electromagnetic waves, with the aid of oscillating circuits. To receive and detect these waves, the other circuits, tuned to same frequency, were used.




*Hertz experiment*

- The frequency of oscillation, $\upsilon = \dfrac{1}{2\pi\sqrt{LC}}$

- Hertz from his experiment produced standing electromagnetic waves and measured the distance between adjacent nodes, to measure the wavelength.

- Knowing the frequency of his resonators, he then found the velocity of the wave from the fundamental wave equation $c = \upsilon\lambda$ and verified that it was the same as that of light, as given by Maxwell.
- The unit of frequency, one cycle per second is named one hertz (1 Hz) in honour of Hertz.

- The plane progressive electromagnetic wave has the following characteristics.
  1. The electric vector, the magnetic vector and the direction of propagation are mutually perpendicular to each other. i.e. the electromagnetic wave is a transverse wave.
  2. The equation of plane progressive electromagnetic wave can be written as

$$E = E_0 \sin\omega\left(t - \frac{x}{c}\right), B = B_0 \sin\omega\left(t - \frac{x}{c}\right), where \;\; \omega = 2\pi\upsilon$$

  This shows that both the electric and magnetic fields oscillate with the same frequency $\upsilon$ and there is no phase difference between them.
  Both these fields have varying time and space and have the same frequency.

- **Velocity** of electromagnetic waves in free space is given by $c = \dfrac{1}{\sqrt{\mu_0\varepsilon_0}} = 3 \times 10^8$ m/s

- The instantaneous magnitude of the electric and magnetic field vectors in electromagnetic wave are related as $\dfrac{|E|}{|B|} = c \;\; or \;\; E = Bc$.

- In a medium of refractive index $n$, the velocity $v$ of an electromagnetic wave is given by $v = \dfrac{c}{n} = \dfrac{1}{n}.\dfrac{1}{\sqrt{\mu_0\varepsilon_0}}$. Also, $v = \dfrac{1}{\sqrt{\mu\varepsilon}}$

  So that $n = \sqrt{\dfrac{\mu\varepsilon}{\mu_0\varepsilon_0}}$

- The energy is equally shared between electric field and magnetic field vectors of electromagnetic wave. Therefore the energy density of the electric field, $u_E = \dfrac{1}{2}\varepsilon_0 E^2$; the energy density of magnetic field, $u_B = \dfrac{1}{2}\dfrac{B^2}{\mu_0}$

- Average energy density of the electric field, $< u_E > = \dfrac{1}{4}\varepsilon_0 E_0^2$ and average energy density of the magnetic field $< u_B > = \dfrac{1}{2}\mu_0 B_0^2 = \dfrac{1}{4}\varepsilon_0 E_0^2$

- Average energy density of electromagnetic wave is $< u > = \dfrac{1}{2}\varepsilon_0 E_0^2$

- **Intensity** of electromagnetic wave is defined as energy crossing per unit area per unit time perpendicular to the directions of propagation of electromagnetic wave. The intensity $I$ is given by the relation $I = < u > c = \dfrac{1}{2}\varepsilon_0 E_0^2 c$

- The electromagnetic wave also carries linear momentum with it. The linear momentum carried by the portion of wave having energy $U$ is given by $p = U/c$.

- If the electromagnetic wave incident on a material surface is completely absorbed, it delivers energy $U$ and momentum $p = U/c$ to the surface.

- If the incident wave is totally reflected from the surface, the momentum delivered to the surface is $U/c - (-U/c) = 2U/c$. It follows that the electromagnetic wave incident on a surface exert a force on the surface.

- According to Maxwell, when a charged particle is accelerated it produces electromagnetic wave. The total radiant flux at any instant is given by $P = q^2\alpha^2 /(6\pi\varepsilon_0 c^3)$ where $q$ is the charge on the particle, and $a$ is its instantaneous acceleration.

- The electromagnetic wave is emitted when an electron orbiting in higher stationary orbit of atom jumps to one of the lower stationary orbit of that atom.

- The electromagnetic waves are also produced when fast moving electrons are suddenly stopped by the metal of high atomic number.

- The total energy flowing perpendicularly per second per unit area in to the surface in free space is called a **poynting vector** $\vec{S}$

  $$\vec{S} = c^2\varepsilon_0(\vec{E}\times\vec{B}) = \frac{\vec{E}\times\vec{B}}{\mu_0}$$

- The S.I. unit of $S$ is **watt/m$^2$ .**

- The rate of energy transfer for electromagnetic wave is proportional to the product of the electric and magnetic field strength, *i.e.* to the surface integral of the poynting vector formed by the component of the field in the plane of the surface.
- The average value of poynting vector ($\vec{S}$) over a convenient time interval in the propagations of electromagnetic wave is known as radiant flux density. When energy of electromagnetic wave is incident on a surface, the flux density is called **intensity of wave** (denoted by $I$). Thus $I = S$.

- The orderly distributions of electromagnetic radiations according to their wavelength or frequency is called the **electromagnetic spectrum**. The below figure and Table shows various regions of electromagnetic spectrum with source, wavelength and frequency ranges of different electromagnetic waves.

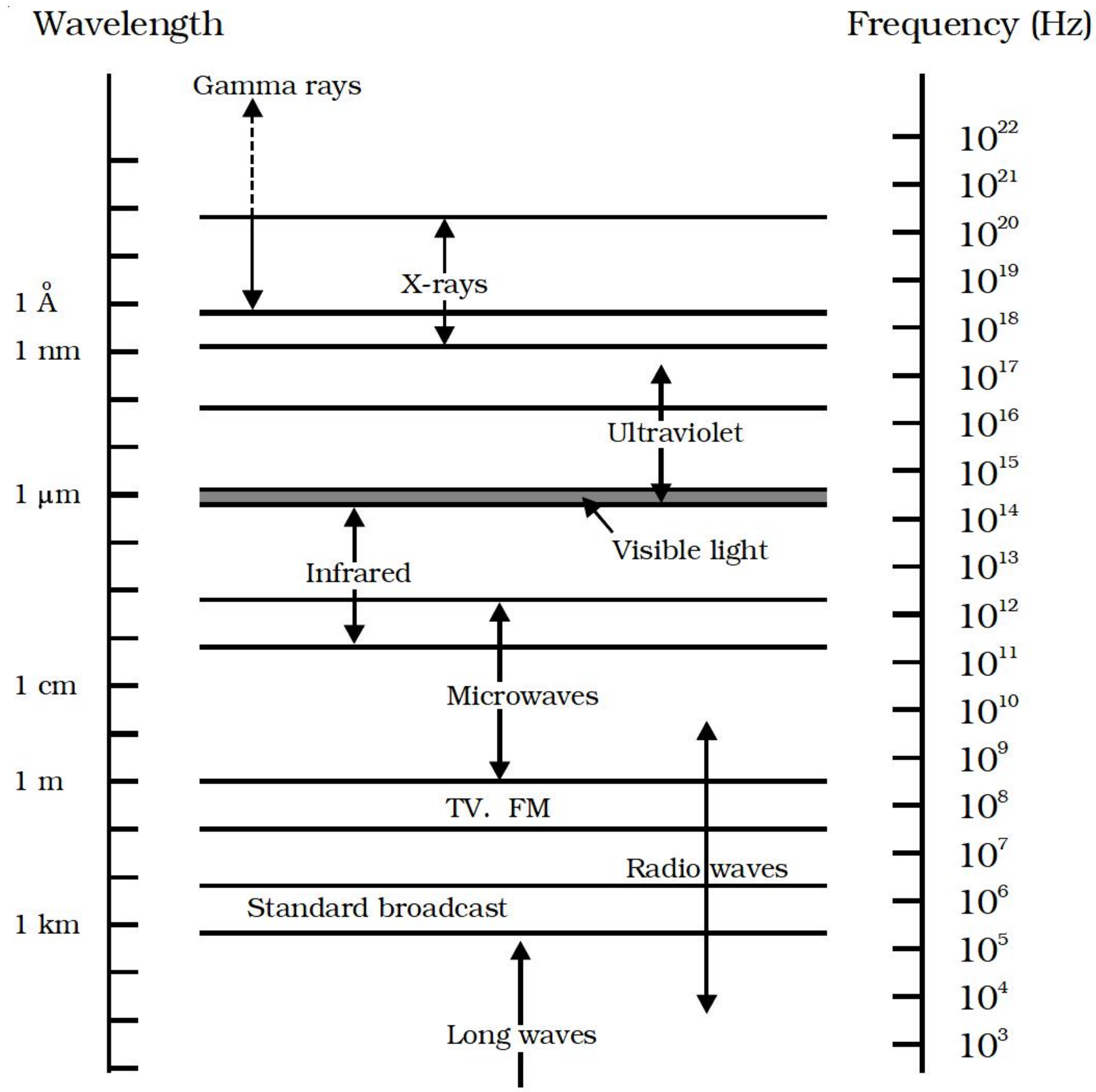
  The following are some of the uses of electromagnetic waves.

  - *Radio waves :* These waves are used in radio and television communication systems. AM band is from 530 kHz to 1710 kHz. Higher frequencies upto 54 MHz are used for short waves bands. Television waves range from 54 MHz to 890 MHz. FM band is from 88 MHz to 108 MHz. Cellular phones use radio waves in ultra high frequency (UHF) band.

  - *Microwaves :* Due to their short wavelengths, they are used in radar communication system. Microwave ovens are an interesting domestic application of these waves.

  - *Infra red waves :*
    (i) Infrared lamps are used in physiotherapy.
    (ii) Infrared photographs are used in weather forecasting.
    (iii) As infrared radiations are not absorbed by air, thick fog, mist etc, they are used to take photograph of long distance objects.
    (iv) Infra red absorption spectrum is used to study the molecular structure.

- *Visible light* the most familiar form of electromagnetic wave, is that part of the spectrum the human eye can detect. The limits of wavelength of the visible region are from 430 nm (violet) to 740 nm (red).
- *Ultra–violet radiations*
(i) They are used to destroy the bacteria and for sterilizing surgical instruments.
(ii) These radiations are used in detection of forged documents, finger prints in forensic laboratories.
(iii) They are used to preserve the food items.
(iv) They help to find the structure of atoms.
- X rays :
(i) X rays are used as a diagonistic tool in medicine.
(ii) It is used to study the crystal structure in solids.
- $\gamma$ rays : Study of $\gamma$ rays gives useful information about the nuclear structure and it is used for treatment of cancer.




The radiowaves can travel from the transmitting antenna to the receiving antenna by the following ways:
(i) ***Ground wave propagation****:*
The lower frequency [500 kHz to 1600 kHz] broadcast service use the surface wave propagation. These waves travel close to the surface of the earth. The electrical conductivity of the earth plays an important role in deciding the propagational characteristics of these waves.

(ii) ***Sky wave propagation****:*

The radiowaves which reach the receiving antenna as a result of reflection from the ionosphere layers are called sky waves. Frequency range from 1500 kHz to 40 MHz is used in sky wave propagation. Due to mutual reflections between the earth and the ionosphere, long distance transmission is possible by the sky waves.

(iii) ***Space wave propagation*** :

The electromagnetic waves which travel directly from the transmitting antenna to the receiving antenna, without being influenced by the earth are called space wave.

| Sl.No. | Name | Source | Wavelength range (m) | Frequency range (Hz) |
|---|---|---|---|---|
| 1. | $\gamma$ – rays | Radioactive nuclei, nuclear reactions | $10^{-14}$ – $10^{-10}$ | $3 \times 10^{22}$ – 3x $10^{18}$ |
| 2. | x – rays | High energy electrons suddenly stopped by a metal target | $1 \times 10^{-10}$–$3 \times 10^{-8}$ | $3 \times 10^{18}$ – $1 \times 10^{16}$ |
| 3. | Ultra–violet (UV) | Atoms and molecules in an electrical discharge | 6 x $10^{-10}$–$4 \times 10^{-7}$ | 5 x $10^{17}$ – $8 \times 10^{14}$ |
| 4. | Visible light | incandescent solids Fluorescent lamps | 4 x $10^{-7}$ – 8 x $10^{-7}$ | 8 x $10^{14}$ – 4 x $10^{14}$ |
| 5. | Infra–red (IR) | molecules of hot bodies | 8 x $10^{-7}$ – 3x $10^{-5}$ | 4 x $10^{14}$ – $1 \times 10^{13}$ |
| 6. | Microwaves | Electronic device (Vacuum tube) | $10^{-3}$ – 0.3 | 3 x $10^{11}$ – 1 x $10^{9}$ |
| 7. | Radio frequency waves | charges accelerated through conducting wires | 10–$10^{4}$ | 3 x $10^{7}$ – 3 x $10^{4}$ |

- Microwaves *i.e.* T.V. and radar waves follow this mode of propagation.
- In the day time, the radiations from the sun reach the earth. At night, the earth's atmosphere prevents the infrared radiations of earth from passing through it and thus helps in keeping the earth's surface warm. This phenomenon is called **green house effect**.
- Electromagnetic waves of frequency less than 30 MHz form amplitude modulated range.
- The electromagnetic waves of frequencies between 80 MHz to 200 MHz form frequency modulated band.
- Height of transmitting antenna (*h*) related with the relation, $d = \sqrt{2hR}$ , where *d* is the radius of the circle on the surface of earth within which the transmitted signal from the transmitting antenna can be received and *R* is the radius of earth.
  Area covered = $\pi d^2 = \pi\ (2hR)$
  Population covered = (area covered) × (population density)

# *ELECTROMAGNETIC WAVES*

**MARKS WEIGHTAGE – 3 marks**

## ***Important Questions and Answers***

**VERY SHORT ANSWER TYPE QUESTIONS (1 MARK)**

1. **Name the EM waves used for studying crystal structure of solids. What is its frequency range? [*AI 2009*]**
**Ans:** *X*-rays, $3 \times 10^{16}$ Hz to $3\times10^{20}$ Hz

2. **Name the part of electromagnetic spectrum whose wavelength lies in the range of 10 –10 m. Give its one use. [*AI 2010*]**
**Ans:** The given range corresponds to X-rays. X-rays are used for detection of fractures, formations of stones etc. in human bodies. They are also used to study crystal structure of solids.

3. **A plane electromagnetic wave travels in vacuum along *z*direction. What can you say about the direction of electric and magnetic field vectors? [*AI 2011*]**
**Ans:** The electric and magnetic field vectors $\vec{E}$ and $\vec{B}$ are perpendicular to each other and also perpendicular to the direction of propagation of the electromagnetic wave. If a plane electromagnetic wave is propagating along the *z*-direction, then the electric field is along *x*-axis, and magnetic field is along *y*-axis.

4. **What are the directions of electric and magnetic field vectors relative to each other and relative to the direction of propagation of electromagnetic waves? [*AI 2012*]**
**Ans:** In an electromagnetic wave $\vec{E}, \vec{B}$ and direction of propagation are mutually perpendicular.

5. **Welders wear special goggles or face masks with glass windows to protect their eyes from electromagnetic radiations. Name the radiations and write the range of their frequency. [*AI 2013*]**
**Ans:** Ultraviolet radiations produced during welding are harmful to eyes. Special goggles or face masks are used to protect eyes from UV radiations. UV radiations have a range of frequency between $10^{15}$ Hz – $10^{17}$ Hz.

6. **Name the part of electromagnetic spectrum which is suitable for :**
**(i) radar systems used in aircraft navigation (ii) treatment of cancer tumours.**
**Ans:** (i) Microwave (ii) $\gamma$-rays.

7. **Name the EM waves used for studying crystal structure of solids. What is its frequency range?**
**Ans:** X-Rays. **Frequency range :** $3 \times 10^{16}$ Hz – $3 \times 10^{19}$ Hz.

8. **Name the electromagnetic radiation which can be produced by klystron or a magnetron valve.**
**Ans:** Electromagnetic radiation produced by a Klystron or a Magnetron valve is **microwave.**

9. **Identify the part of the electromagnetic spectrum to which the following wavelengths belong: (i) $10^{-1}$ m (ii) $10^{-12}$ m**
**Ans:** (i) $10^{-1}$ m = 10 cm belongs to **short radiowaves.**
(ii) $10^{-12}$ m = 0· 01 m belongs to **gamma rays.**

10. **Name the part of the electromagnetic spectrum of wavelength $10^{-2}$ m and mention its one application.**

**Ans:** Wavelength $10^{-2}$ m belongs to **microwaves.** It is used in RADAR.

**11. In what way can the setting up of transmission tower by a mobile company in a residential colony prove to be injurious to health?**
**Ans:** Electromagnetic radiations emitted by an antenna can cause cancer, cardiac problem and headache.

**12. Name the em waves which are suitable for radar systems used in aircraft navigation. Write the range of frequency of these waves.**
**Ans:** Microwaves Frequency range : $10^{10}$ Hz to $10^{12}$ Hz

**13. If the earth did not have atmosphere, would its average surface temperature be higher or lower than what it is now? Explain.**
**Ans:** Average surface temperature will be lower. This is because there will be no green house effect in absence of atmosphere.

**14. An em wave exerts pressure on the surface on which it is incident. Justify.**
**Ans:** An electromagnetic wave exerts pressure on the surface on which it is incident because these waves carry both energy and momentum.

**15. Name the em waves which are used for the treatment of certain forms of cancer. Write their frequency range.**
**Ans:** X rays or $\gamma$ rays Range: $10^{18}$ Hz to $10^{22}$ Hz.

**16. Thin ozone layer on top of stratosphere is crucial for human survival. Why?**
**Ans:** Ozone layer absorbs the ultraviolet radiations from the sun and prevents it from reaching the earth's surface.

**17. Why is the amount of the momentum transferred by the em waves incident on the surface so small?**
**Ans:** Momentum transferred, $p = \frac{u}{c}$ where $u$ = energy transferred and $c$ = speed of light
Due to the large value of speed of light ($c$), the amount of momentum transferred by the em waves incident on the surface is small.

**18. Name the em waves which are produced during radioactive decay of a nucleus. Write their frequency range.**
**Ans:** em waves : $Y$-rays Range : $10^{19}$ Hz to $10^{23}$ Hz

**19. Welders wear special glass goggles while working. Why? Explain.**
**Ans:** This is because the special glass goggles protect the eyes from large amount of UV radiations produced by welding arcs.

**20. Why are infrared waves often called as heat waves? Give their one application.**
**Ans:** Infrared waves are called heat waves because water molecules present in the materials readily absorb the infra red rays get heated up.
**Application:** They are used in green bouses to warm the plants.

**21. To which part of the electromagnetic spectrum does a wave of frequency $5 \times 10^{19}$ Hz belong?**
**Ans:** X-rays or $\gamma$-rays.

**22. To which part of the electromagnetic spectrum does a wave of frequency $3 \times 10^{13}$ Hz belong?**
**Ans:** Infrared radiation

**23. To which part of the electromagnetic spectrum does a wave of frequency $5 \times 10^{11}$ Hz belong?**
**Ans:** Microwaves or short radiowaves.

**24. Arrange the following electromagnetic waves in order of increasing frequency:**
**γ-rays, microwaves, infrared rays and ultraviolet rays.**
**Ans:** Microwave < Infrared < Ultraviolet < γ-rays

**SHORT ANSWER TYPE QUESTIONS (2 MARKS/3 MARKS)**

**25. Optical and radio telescopes are built on the ground while *X*ray astronomy is possible only from the satellites orbiting the Earth. Why?**
**Ans:** Atmosphere absorbs *X*-rays, so *X*-ray astronomy is possible only from satellites orbiting the earth. Visible and radiowaves can penetrate through the atmosphere, so optical and radio telescopes are build on the ground.

**26. The small ozone layer on top of the stratosphere is crucial for human survival. Why? [*AI 2009*]**
**Ans:** Ozone layer absorbs ultraviolet radiations from sun and prevents it from reaching the earth's surface and hence is crucial for human survival, as ultraviolet radiations are harmful to human beings.

**27. How are infrared waves produced? Why are these referred to as heat waves? Write their one important use? [*AI 2011*]**
**Ans:** Infrared waves are produced by hot bodies and molecules. This band lies adjacent to the low frequency or long wavelength end of the visible spectrum. Infrared waves are referred to as heat waves, because water molecules present in most materials readily absorb infrared waves (many other molecules, for example, $CO_2$, $NH_3$ also absorb infrared waves). After absorption, their thermal motion increases, that is they heat up and heat their surroundings.
Infrared rays are used in green house effect.

**28. A capacitor of capacitance 'C' is being charged by connecting it across a dc source along with an ammeter. Will the ammeter show a momentary deflection during the process of charging? If so, how would you explain this momentary deflection an the resulting continuity of current in the circuit? Write the expression for the current inside the capacitor. [*AI 2012*]**
**Ans:** Yes, ammeter will show a momentary deflection. The momentary deflection is due to the flow of electrons in the circuit during the charging process. During the charging process the electric field between the capacitor plates is changing and hence a displacement current flows in the gap. Hence we can say that there is a continuity of current in the circuit.
Expression, $I_d = \varepsilon_0 \dfrac{d\phi}{dt}$

**29. How does oscillating charge produce electromagnetic waves?**
**Ans:** An oscillating charge produces an oscillating electric field in space, which produces an oscillating magnetic field. The oscillating electric and magnetic fields regenerate each other, and this results in the production of em waves in space.

**30. The oscillating magnetic field in a plane electromagnetic wave is given by**

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

**(i) Calculate the wavelength of the electromagnetic wave.**
**(ii) Write down the expression for the oscillating electric field.**
**Ans:**
Standard equation of magnetic field is
$B_y = B_0 \sin (\omega t + kx) \ T$
Comparing this equation with the given equation, we get
$B_0 = 8 \times 10^{-6}$ T, $\omega = 2 \times 10^{11}$ rad s$^{-1}$, $k = \dfrac{2\pi}{\lambda} = 300\pi$

wavelength, $\lambda = \frac{2\pi}{300\pi} = \frac{1}{150} m$

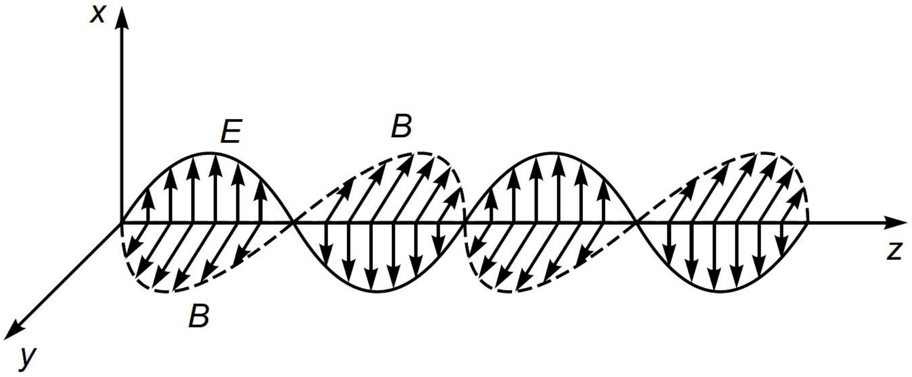
(ii) $E_0 = B_0c = 8 \times 10^{-6} \times 3 \times 10^8 = 2 \cdot 4 \times 10^3$ $Vm^{-1}$.

According to right hand system of $\vec{\mathbf{E}}, \vec{\mathbf{B}}, \vec{\mathbf{K}}$, the electric field oscillates along negative $Z$-axis, so equation is

$E_Z = -\, 2{\cdot}4 \times 10_3 \sin (2 \times 10^{11}\, t + 300\pi x)$ $Vm^{-1}$

**31. Sketch a schematic diagram depicting oscillating electric and magnetic fields of an em wave propagating along + z-direction.**

**Ans:** Electric field is along $x$-axis and magnetic field is along $y$-axis.




**32. The oscillating electric field of an electromagnetic wave is given by:**

$$E_y = 30 \sin [2 \times 10^{11}\, t + 300\, \pi x]\ Vm^{-1}$$

**(a) Obtain the value of the wavelength of the electromagnetic wave.**

**(b) Write down the expression for the oscillating magnetic field.**

**Ans:** (a) Given equation is $E_y = 30 \sin (2 \times 10^{11}\, t + 300\, \pi x)$ $Vm^{-1}$

Comparing with standard equation

$E_y = E_0 \sin (\omega t + kx)$ $Vm^{-1}$, we get

$E0 = 30$ $Vm^{-1}$, $\omega = 2 \times 10^{11}$ rad $s^{-1}$, $k = \frac{2\pi}{\lambda} = 300\pi m^{-1}$

$\therefore$ Wavelength, $\lambda = \frac{2\pi}{300\pi} = \frac{1}{150} m = 6.67 \times 10^{-3} m$

(b) The wave is propagating along $X$-axis, electric field is oscillating along $Y$-axis, so according to right hand system of ($\vec{\mathbf{E}}, \vec{\mathbf{B}}, \vec{\mathbf{K}}$) the magnetic field must oscillate along $Z$-axis.

$\therefore\ B_0 = \frac{E_0}{C} = \frac{30}{3 \times 10^8} = 10^{-7} T$

$\therefore$ Equation of oscillating magnetic field is

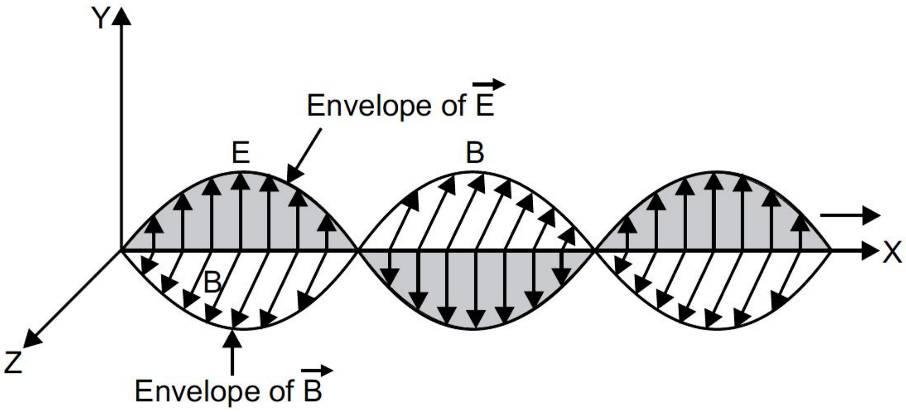
$B_Z = B_0 \sin (\omega t + kx)\ T$

$\Rightarrow B_z = 10^{-7} \sin (2 \times 10^{11}\, t + 300\, \pi x)\ T$

**33. What is meant by the transverse nature of electromagnetic waves ? Draw a diagram showing the propagation of an electromagnetic wave along the $x$-direction, indicating clearly the directions of the oscillating electric and magnetic fields associated with it.**

**Ans: Transverse Nature of Electromagnetic Waves:**

In an electromagnetic wave, the electric and magnetic field vectors oscillate, perpendicular to the direction of propagation of wave. This is called transverse nature of electromagnetic wave. In an electromagnetic wave, the three vectors $\vec{\mathbf{E}}, \vec{\mathbf{B}}$ **and** $\vec{\mathbf{K}}$ form a right handed system. Accordingly if a wave is propagating along $X$-axis, the electric field vector oscillates along $Y$-axis and magnetic field vector oscillates along $Z$-axis. Diagram is shown in fig.




**34. How does a charge *q* oscillating at certain frequency produce electromagnetic waves?**

**Ans:** An oscillating electric charge produces oscillating electric field, which produces oscillating magnetic field; which in turn produces oscillating electric field and so on; thereby producing an electromagnetic wave propagating in free space.

**35. Arrange the following electromagnetic radiations in ascending order of their frequencies:**
**(*i*) Microwave**
**(*ii*) Radio wave**
**(*iii*) X-rays**
**(*iv*) Gamma rays**
**Write two uses of any one of these.**

**Ans:** In ascending power of frequencies: radiowaves, microwaves, ultraviolet rays, *X*-rays and gamma
rays.

Uses of Electromagnetic Spectrum

(*i*) **γ-rays** are highly penetrating, they can penetrate thick iron blocks. Due to high energy, they are used to produce nuclear reactions. γ-rays are produced in nuclear reactions. In medicine, they are used to destroy cancer cells.

(*ii*) ***X*-rays** are used in medical diagnostics to detect fractures in bones, tuberculosis of lungs, presence of stone in gallbladder and kidney. They are used in engineering to check flaws in bridges. In physics *X*-rays are used to study crystal structure.

(*iii*) **Radiowaves** are used for broadcasting programmes to distant places. According to frequency range, they are divided into following groups

(1) Medium frequency band or medium waves 0·3 to 3 MHz
(2) Short waves or short frequency band 3 MHz — 30 MHz
(3) Very high frequency (VHF) band 30 MHz to 300 MHz
(4) Ultrahigh frequency (UHF) band 300 MHz to 3000 MHz

(*iv)* **Microwaves** are produced by special vacuum tubes, namely; klystrons, magnetrons and gunn diodes. Their frequency range is 3 GHz to 300 Ghz. They are used in radar systems used in air craft navigation and microwave users in houses.