ELECTROMAGNETIC WAVES

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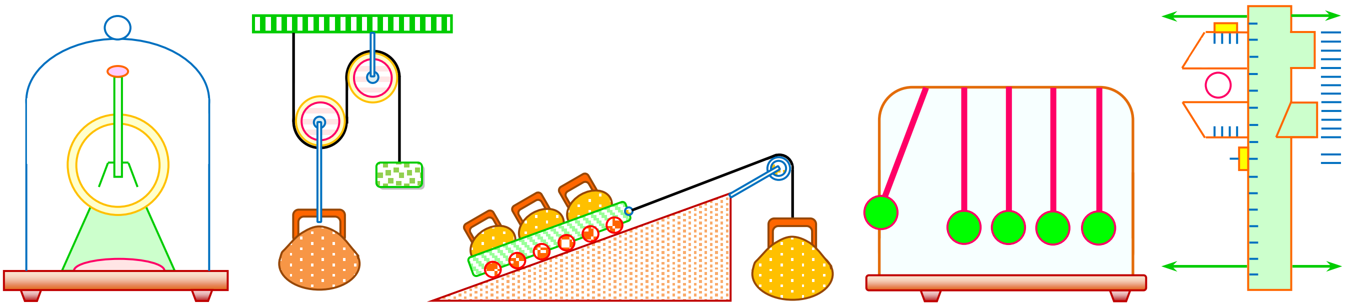
PHYSICS XII



PHYSICS BOOKLET FOR JEE NEET & BOARDS

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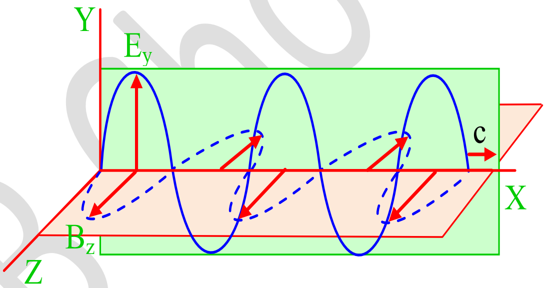
ELECTROMAGNETIC WAVES

1 INTRODUCTION

A changing electric field produces a changing magnetic field and vice versa which gives rise to a transverse wave known as electromagnetic waves. The time varying electric field and magnetic field mutually perpendicular to each other also perpendicular to the direction of propagation.

Thus the electromagnetic waves consist of sinusoidally time varying electric and magnetic field acting at right angles to each other as well as at right angles to the direction of propagation.



2 HISTORY OF ELECTROMAGNETIC WAVES

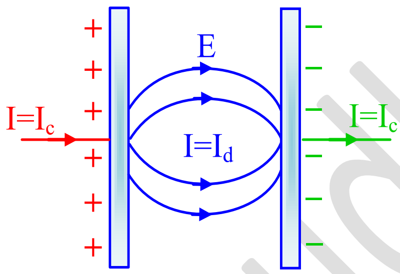
- In the year 1865, Maxwell predicted the electromagnetic waves theoretically. According to him, an accelerated charge sets up a magnetic field in its neighborhood.
- In 1887, Hertz produced and detected electromagnetic waves experimentally at wavelength of about 6m.
- Seven year later, J.C. Bose became successful in producing electromagnetic waves of wavelength in the range 5mm to 25 mm.
- In 1896, Marconi discovered that if one of the spark gap terminals is connected to an antenna and the other terminal is earthed, the electromagnetic waves radiated could go upto several kilometers.
- The antenna and the earth wires from the two plates of a capacitor which radiates radio frequency waves. These waves could be received at a large distance by making use of an antenna earth system as detector.
- Using these arrangements, in 1899 Marconi first established wireless communication across the English channel i.e., across a distance of about 50 km.

3 CONCEPT OF DISPLACEMENT CURRENT

When a capacitor is allowed to charge in an electric circuit, the current flows through connecting wires. As capacitor charges, charge accumulates on the two plates of capacitor and as a result, a changing electric field is produced across between the two plate of the capacitor.

According to Maxwell changing electric field intensity is equivalent to a current through capacitor that current is known as displacement current (I_0). If +q and –q be the charge on the left and right plates of the capacitor respectively at any instant if σ be the surface charge density of plate of capacitor the electric field between the plate is given by

$$E = \frac{\sigma}{\epsilon_0} = \frac{q}{\epsilon_0 A}$$



charge on the plates of the capacitor increased by dq in time dt then dq = I dt

change in electric field is

$$dE = \frac{dq}{\epsilon_0 A} = \frac{Idt}{\epsilon_0 A} \Rightarrow \frac{dE}{dt} = \frac{I}{\epsilon_0 A}$$

$$I = \epsilon_0 A\frac{dE}{dt} = \epsilon_0 \frac{d}{dt}(EA) = \epsilon_0 \frac{d\phi_E}{dt} \quad (\because \phi_E = EA)$$

$$\boxed{I_d = \epsilon_0 \frac{d\phi_E}{dt}}$$

The conduction current is the current due to the flow of charges in a conductor and is denoted as I_c and **displacement current** is the current due to changing electric field between the plate of the capacitor and denoted as I_d so the total current I is sum of I_c and I_d i.e. $I = I_c + I_d$

Ampere's circuital law can be written as

$$\oint \vec{B}.\vec{d\ell} = \mu_0(I_c + I_d) \Rightarrow \oint \vec{B}.\vec{d\ell} = \mu_0(I_c + \epsilon_0 \frac{d\phi_E}{dt})$$

Illustration 1: ***In a plane electromagnetic wave, the electric field oscillates sinusoidally at a frequency 2×10^{10} Hz and amplitude 48 V/m. The amplitude of oscillating magnetic field will be:***

(A) $\frac{1}{16}\times 10^{-8}$ *Wb/m²* *(B)* 16×10^{-8} *Wb/m²*

(C) 12×10^{-7} *Wb/m²* *(D)* $\frac{1}{12}\times 10^{-7}$ *Wb/m²*

Solution: (B) Oscillating magnetic field

$$B = \frac{E}{c} = \frac{48}{3\times 10^8} = 16 \times 10^{-8}\ Wb/m^2$$

Illustration 2: ***A parallel plate capacitor of plate separation 2 mm is conncected in an electric circuit having source voltage 400V. If the plate area is 60 cm^2, then the value of displacement current for 10^{-6} sec. will be:***

(A) 1.062A ***(B) 1.062 $\times 10^{-2}$A***

(C) 1.062 $\times 10^{-3}$A ***(D) 1.062 $\times 10^{-4}$A***

Solution: (D) $I_D = \varepsilon_0 \frac{\partial \phi_E}{\partial t} = \varepsilon_0 \frac{EA}{t} = \frac{\varepsilon_0 VA}{dt}$

or $I_D = \frac{8.85 \times 10^{-12} \times 400 \times 60 \times 10^{-4}}{2 \times 10^{-3} \times 10^{-6}} = 1.062 \times 10^{-4}$A

Illustration 3: ***In an electric circuit, there is a capacitor of reactance 100Ω connected across the source of 220V. The displacement current will be:***

(A) 2.2A ***(B) 0.22A*** ***(C) 4.2A*** ***(D) 2.4A***

Solution: (A) Displacement current and conduction current are equal.

$$\therefore I_D = \frac{E}{Z} = \frac{220}{100} = 2.2A$$

4 MAXWELL'S EQUATIONS AND LORENTZ FORCE

The existence of electro-magnetic waves that propagate through the space in the form of varying electric and magnetic fields has been predicted by the four basic laws of electromagnetism which are called **Maxwell's equations.**

(i) Gauss's law in electrostatics: It states that the total electric flux through any closed surface is equal to $\frac{1}{\varepsilon_0}$ times the net charge enclosed by

Mathematically,

$$\oint \vec{E}.\vec{ds} = \frac{q}{\epsilon_0}$$

This equation is called Maxwell's first equation.

(ii) Gauss'law in magnetism: It states that the net magnetic flux crossing any closing surface is always zero.

Mathematically,

$$\oint \vec{B}.\vec{ds} = 0$$

This equation is called Maxwell's second equation. A direct consequence of this equation is that the magnetic monpoles do not exist.

(iii) Faradays's law of electromagnetic induction: It states that the induced emf produced in a circuit is numerically equal to the rate of change of magnetic flux through it.

Mathematically,

$$\varepsilon = -\frac{d\phi_B}{dt}$$

$$\text{emf} = \oint \vec{E}.\vec{d\ell} = -\frac{d\phi_B}{dt}$$

This equation is called Maxwell's third equation.

The negative sign in this equation indicates that the induced emf produced opposes the rate of change of magnetic flux.

Illustration 4: ***A point source of electromagnetic radiation has an average power output of 800W. The maximum value of electric field at a distance 3.5m from the source will be:***

(A) 56.7 V/m ***(B) 62.6 V/m*** ***(C) 39.3 V/m*** ***(D) 47.5 V/m***

Solution: (B) Intensity of electromagnetic wave given is by

$$I = \frac{P_{av}}{4\pi r^2} = \frac{E^2 m}{2\mu_0 c}$$

$$E_m = \sqrt{\frac{\mu_0 c P_{av}}{2\pi r^2}}$$

$$= \sqrt{\frac{(4\pi \times 10^{-7}) \times (3 \times 10^8) \times 800}{2\pi \times 3.5^2}} = 62.6 \text{ V/m}$$

Illustration 5: ***In the above problem, the maximum value of magnetic field will be:***

(A) 2.09×10^{-5} T ***(B) 2.09×10^{-6} T***

(C) 2.09×10^{-7} T ***(D) 2.09×10^{-7} T***

Solution: (C) The maximum value of magnetic field is given by

$$B_m = \frac{E_m}{c} = \frac{62.6}{3 \times 10^8}$$

$= 2.09 \times 10^{-7}$ T

(iv) **Maxwell-Ampere circuital law**: It states that the line integral of magnetic field along a closed path is equal to μ_0 times the total current (i.e., sum of conduction and displacement currents threading the surface bounded by that closed path)

Mathematically, $\oint \vec{B}.\vec{d\ell} = \mu_0 \left[I_c + \epsilon_0 \frac{d\phi_E}{dt} \right]$

This equation is called **Maxwell's fourth equation**.

(v) **Lorentz:** The vector sum of electric force and magnetic force on any charged particle is called the Lorentz force.

$$\vec{F} = q[\vec{E} + (\vec{v}\ '\ \vec{B})]$$

The above five equations give a complete description of all electromagnetic interactions.

SUMMARY:

There are four maxwell's equation are given below

(1) Gauss law in electrostatics : $\oint \vec{E}.\vec{ds} = \frac{q}{\epsilon_0}$ ***....(i)***

(2) Guass law in magnetism : $\oint \vec{B}.\vec{ds} = 0$ ***...(ii)***

(3) Faraday's law of electromagnetic induction :

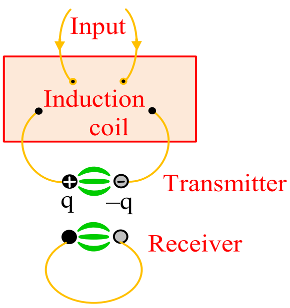
emf = $\oint \vec{E}.\vec{d\ell} = -\frac{d\phi_B}{dt}$ ***...(iii)***

(4) Maxwell - Ampere's circuital law :

$\oint \vec{B}.\vec{d\ell} = \mu_0 \left[I_c + \epsilon_0 \frac{d\phi_E}{dt} \right]$ ***....(iv)***

5 HERTZ EXPERIMENT (PRACTICAL PRODUCTION OF EM WAVES)

- In 1888, Hertz demonstrated the production of electromagnetic waves by oscillating charge. His experimental apparatus is shown schematically in figure.



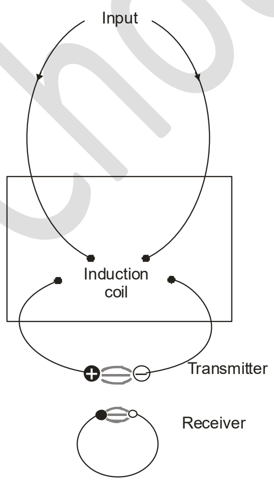
- An induction coil is connected to two spherical electrodes with a narrow gap between them. It acts as a transmitter. The coil provides short voltage surges to the spheres making one positive and the other negative. A spark is generated between the spheres when the voltage between them reaches the breakdown voltage for air. As the air in the gap is ionized, it conducts more rapidly and the discharge between the spheres becomes oscillatory.
- The above experimental arrangement is equivalent to an LC circuit, where the inductance is that of the loop and the capacitance is due to the spherical electrodes.
- Electromagnetic waves are radiated at very high frequency ($\approx$ 100 MHz) as a result of oscillation of free charges in the loop.
- Hertz was able to detect these waves using a single loop of wire with its own spark gap (the receiver).
- Sparks were induced across the gap of the receiving electrodes when the frequency of the receiver was adjusted to match that of the transmitter.

6 PRODUCTION OF ELECTROMAGNETIC WAVES

(i) **According to Maxwell**, an accelerated charge sets up a magnetic field in its neighbourhood. The magnetic field, in turn, produces an electric field in that region. Both these fields vary with time and act as sources for each other.

(ii) As oscillating charge is accelerated continuously, it will radiate electromagnetic waves continuously.

(iii) In 1988, Hertz demonstrated the production of electromagnetic apparatus is shown schematically in fig.



(iv) An induction coil is connected to two spherical electrodes with a narrow gap between them. It acts as a transmitter. The coil provides short voltage surges to the spheres making one positive and the other negative. A spark is generated between the spheres when the voltage between them reaches the breakdown voltage for air. As the air in the gap is ionised, it conducts more rapidly and the discharge between the spheres becomes oscillatory.

(v) The above experiment arrangment is equivalent to an LC circuit, where the inductance is that of the loop and the capacitance is due to the spherical electrodes.

(vi) Electromagnetic waves are radiated at very high frequency($\approx$100 MHz) as a result of oscillation of free charges in the loop.

(vii) Hertz was able to detect these waves using a single loop of wire with its own spark gap (the receiver).

(viii) Sparks were induced across the gap of the receiving electrodes when the frequency of the receiver was adjusted to match that of the transmitter.

7 PROPERTIOES OF ELECTROMAGNETIC WAVES

- The electric and magnetic fields satisfy the following wave equations, which can be obtained from Maxwell's third and fourth equations.

  $\frac{\partial^2 E}{\partial x^2} = \mu_0\varepsilon_0 \frac{\partial^2 E}{\partial t^2}$ and $\frac{\partial^2 B}{\partial x^2} = \mu_0\varepsilon_0 \frac{\partial^2 B}{\partial t^2}$

- Electromagnetic waves travel through vacuum with the speed of light c, where

  $c = \frac{1}{\sqrt{\mu_0\varepsilon_0}} = 3 \times 10^8$ m/s

- The electric and magnetic fields of an electromagnetic wave are perpendicular to each other and also perpendicular to the direction of wave propagation. Hence, these are transverse waves.
- The instantaneous magnitudes of $\vec{E}$ and $\vec{B}$ in an electromagnetic wave are related by the expression $\frac{E}{B} = c$
- Electromagnetic waves carry energy. The rate of flow of energy crossing a unit area is described by the Poynting vector $\vec{S}$. Where $\vec{S} = \frac{1}{\mu_0}\vec{E}\times\vec{B}$.
- Electromagnetic waves carry momentum and hence can exert pressure (P) on surfaces, which is known as radiation pressure. For an electromagnetic wave with Poynting vector $\vec{S}$, incident upon a perfectly absorbing surface $P = \frac{S}{c}$ and if incident upon a perfectly reflecting surface $P = \frac{2S}{c}$.
- The electric and magnetic fields of a sinusoidal plane electromagnetic wave propagating in the positive x-direction can also be written as

  $E = E_m\sin(kx - \omega t)$ and

  $B = B_m\sin(kx - \omega t)$

  where ω is the angular frequency of the wave and k is wave number which are given by

  $\omega = 2\pi f$ and $k = \frac{2\pi}{\lambda}$

- The intensity of a sinusoidal plane electro-magnetic wave is defined as the average value of Poynting vector taken over one cycle.

  $S_{av} = \frac{E_m B_m}{2\mu_0} = \frac{E_m^2}{2\mu_0 c} = \frac{c}{2\mu_0}B_m^2$

- The fundamental sources of electromagnetic waves are accelerating electric charges. For examples radio waves emitted by an antenna arise from the continuous oscillations (and hence acceleration) of charges within the antenna structure.
- Electromagnetic waves obey the principle of superposition.
- The electric vector of an electromagnetic field is responsible for all optical effects, for this reason electric vector is also called a light vector.

Illustration 6: ***In an electromagnetic wave, the amplitude of electric field is 1V/m. The frequency of wave is 5×10^{-14} Hz. The wave is propagating along z-axis. The average energy density of electric field, in Joule/m^3, will be:***

(A) 1.1×10^{-11} (B) 2.2×10^{-12} (C) 3.3×10^{-13} (D) 4.4×10^{-14}

Solution: (B) Average energy density is given by

$$u_E = \frac{1}{2}\varepsilon_0 E^2 = \frac{1}{2}\varepsilon_0\left(\frac{E_0}{\sqrt{2}}\right)^2 = \frac{1}{4}\varepsilon_0 E_0^2$$

$$= \frac{1}{4}\times 0.85\times 10^{-12}\times(1)^2$$

$= 2.2 \times 10^{-12}$ J/m^3

Illustration 7: ***To establish an instantaneous displacement current of 2A in the space between two parallel plates of 1μF capacitor, the potential difference across the capacitor plates will have to be changed at the rate of:***

(A) 4×10^4 V/s (B) 4×10^6 V/s

(C) 2×10^4 V/s (D) 2×10^6 V/s

Solution: (D) $I_D = \varepsilon_0 \frac{d\phi_E}{dt} = \varepsilon_0 \frac{d}{dt}(EA) = \varepsilon_0 A \frac{d}{dt}\left(\frac{V}{d}\right)$

या $I_D = \frac{\varepsilon_0 A dV}{d\ dt} = C\frac{dV}{dt}$

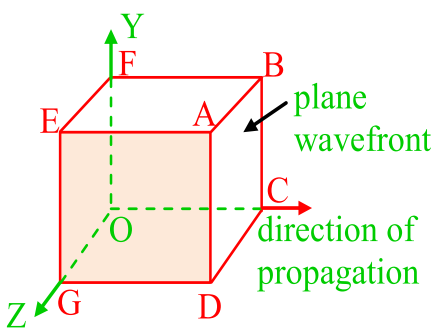
$$\therefore \frac{dV}{dt} = \frac{I_D}{C} = \frac{2}{10^{-6}} = 2\times 10^6 V/s$$

8 TRANSVERSE NATURE OF ELECTROMAGNETIC WAVES

Maxwell showed that a changing electric field produces a changing magnetic field and vice-versa. This alternate production of time 'varying electric and magnetic fields gives rise to the propagation of electromagnetic waves. The variation of electric field ($\vec{E}$) and magnetic field ($\vec{B}$) are mutually perpendicular to each other as well as the direction of the propagation of the wave i.e., the electromagnetic waves are transverse in nature.

Proof :

Consider a plane electromagnetic wave traveling along X-direction with its wave front in the Y-Z plane and ABCD is its portion at time t. The values of electric field and magnetic field to the left of ABCD will depend on x and t (and not on y and z as the wave under consideration is a plane wave propagating in x direction.



According to Gauss' law, the total electric flux across the parallelopiped' ABCDOEFG is zero because it does not enclose any charge, i.e. $\oint \vec{E}.\vec{dS} = 0$

or $\oint_{ABCD} \vec{E}.\vec{dS} + \oint_{EFOG} \vec{E}.\vec{dS} + \oint_{ADGE} \vec{E}.\vec{dS} + \oint_{BCOF} \vec{E}.\vec{dS}$

$$+ \oint_{OCDG} \vec{E}.\vec{dS} + \oint_{FBAE} \vec{E}.\vec{dS} = 0 \qquad ....(i)$$

since electric field $\vec{E}$ does not depend on y and z, so the contribution to the electric flux coming from the faces normal to y and z axes cancel out in pairs.

i.e., $\oint_{OCDG} \vec{E}.\vec{dS} + \oint_{FBAE} \vec{E}.\vec{dS} = 0 \qquad ....(ii)$

and $\oint_{ADGE} \vec{E}.\vec{dS} + \oint_{BCOF} \vec{E}.\vec{dS} = 0 \qquad ...(iii)$

Using equation (ii) and (iii) in equation (i), we get

$$\oint_{ABCD} \vec{E}.\vec{dS} + \oint_{EFOG} \vec{E}.\vec{dS} = 0 \qquad ...(iv)$$

Now

$$\oint_{ABCD} \vec{E}.\vec{dS} = \oint_{ABCD} E_x.dS\cos 0 = \oint_{ABCD} E_x\, dS = E_x \oint_{ABCD} dS$$

$$(\because \vec{E}_x \text{ is parallel to } \vec{dS})$$

$= E_x \times$ area of face ABCD $= E_xS \qquad ...(v)$

and $\oint_{EFOG} \vec{E'}.\vec{dS} = \oint_{EFOG} E'_x dS\cos 180^o = E'_x \oint_{EFOG} dS$

$$(\because \vec{E'}_x \text{ is antiparallel to } \vec{dS})$$

$= E'_x \times$ area of face EFOG $= E'_xS \qquad ....(vi)$

where, E_x and E'_x are the x-components of electric field on the faces ABCD and EFOG respectively.

Substituting the values of equations (v) and (vi) in equation (iv), we get

$E_xS - E'_xS = 0$ or $S(E_x - E'_x) = 0$

$\because S \neq 0$

$\therefore E_x - E'_x = 0$ or $\boxed{E'_x = E_x}$

This equation shows that the value of the x-component of electric field does not change with time. In other words, electric field along x-axis is static.

Since the static electric field cannot propagate the wave, hence the electric field parallel to the direction of the propagation of the wave is zero.

i.e. $E'_x = E_x = 0$

It means, electric field is perpendicular to the direction of propagation of the wave.

similarly, it can be proved that the magnetic field is perpendicular to the direction of the propagation of the wave.

Since both electric and magnetic fields are perpendicular to the direction of the propagation of the wave, so electromagnetic wave is transverse in nature.

9 IMPORTANT POINTS TO REMEMBER

- *When a capacitor is connected across the battery through the connecting wires there is flow of conduction current, while through the gap between the plates of capacitor, there is flow of displacement current.*
- *Maxwell's equation are mathematical formulation of Gauss's law in electrostatics (I) Gauss's law in electromagnetism(II) faradays law of electromagnetic induction (III) and Ampere's circuital law (IV)*
- *Frequency of electromagnetic waves is its inherent characterstic when an electromagnetic wave travels from one medium to another, its wavelength changes but frequency remains unchanged.*
- *Ozone layer absorbs the ultra-violet rays from the sun and these prevents them from producing harmful effect on living organisms on the earth. Further it traps the infra-red rays and prevents them from escaping the surface of earth. It helps to keeps the earth's at atmosphere warm.*

Ex.1 In a plane electromagnetic wave, the electric field oscillates sinusoidally at a frequency of 2×10^{10} Hz and amplitude 48 V/m. The amplitude of oscillating magnetic field will be-

Sol. Oscillating magnetic field

$$B = \frac{E}{c} = \frac{48}{3\times10^8} = 16 \times 10^{-8}\ \text{Wb/m}^2$$

Ex.2 In the above problem, the wavelength of the wave will be-

Sol. Wavelength of electromagnetic wave

$$\lambda = \frac{c}{\nu} = \frac{3\times10^8}{2\times10^{10}} = 1.5 \times 10^{-2} = 1.5\ \text{cm}$$

Ex.3 A point source of electromagnetic radiation has an average power output of 800 W. The maximum value of electric field at a distance 3.5 m from the source will be-

Sol. Intensity of electromagnetic wave given is by

$$I = \frac{P_{av}}{4\pi r^2} = \frac{E^2 m}{2\mu_0 c}$$

$$E_m = \sqrt{\frac{\mu_0 c P_{av}}{2\pi r^2}} = \sqrt{\frac{(4\pi\times10^{-7})\times(3\times10^8)\times800}{2\pi\times35^2}}$$

$$= 62.6\ \text{V/m}$$

Ex.4 In the above problem, the maximum value of magnetic field will be-

Sol. The maximum value of the magnetic field is given by $B_m = \frac{E_m}{c} = \frac{62.6}{3\times10^8} = 2.09 \times 10^{-7}$ T

Ex.5 What should be the height of transmitting antenna if the T.V. telecast is to cover a radius of 128 km ?

Sol. Height of transmitting antenna

$$h = \frac{d^2}{2R_e} = \frac{(128\times10^3)^2}{2\times6.4\times10^6} = 1280\ \text{m}$$

Ex.6 The area to be covered for T.V. telecast is doubled, then the height of transmitting antenna (T.V tower) will have to be-

Sol. The area of transmission of surrounding the T.V. tower $A = \pi d^2 = \pi(2hRe)$ $A \propto h$

Ex.7 In an electromagnetic wave, the amplitude of electric field is 1 V/m. The frequency of wave is 5×10^{14} Hz. The wave is propagating along z-axis. The average energy density of electric field, in Joule/m^3, will be-

Sol.8 Average energy density is given by

$u_E = \frac{1}{2}\varepsilon_0 E^2 = \frac{1}{2}\varepsilon_0\left(\frac{E_0}{\sqrt{2}}\right)^2 = \frac{1}{4}\varepsilon_0 E_0^2$

$= \frac{1}{4} \times 8.85 \times 10^{-12} \times (1)^2 = 2.2 \times 10^{-12}$ J/m^2

Ex.8 A T.V. tower has a height of 100 m. How much population is covered by T.V. broadcast, if the average population density around the tower is 1000/km^2 ?

Sol. Radius of the area covered by T.V. telecast

$d = \sqrt{2hR_e}$

Total population covered = πd^2 × population density = $2\pi hR_e$ × polulation density

$= 2 \times 3.14 \times 100 \times 6.4 \times 10^6 \times \frac{1000}{10^6}$

$= 39.503 \times 10^5$

Ex.9 An electromagnetic radiation has an energy 14.4 KeV. To which region of electromagnetic spectrum does it belong ?

Sol. $\lambda = \frac{hc}{E} = \frac{6.6\times10^{-34}\times3\times10^8}{14.4\times10^3\times1.6\times10^{-19}}$

$= 0.8 \times 10^{-10}$m = 0.8 Å

This wavelength belongs to X-ray region.

10 VARIOUS PARTS OF ELECTROMAGNETIC SPECTRUM

S. No.	Radiation	Discover	How produced	Wavelength range	Frequency range	Energy range	Properties	Application
1.	γ-Rays	Henry Becquerel and Madam Cuire	Due to decay of radioactive nuclei.	10^{-14} m to 10^{-10} m	3×10^{-22} Hz to 3×10^{18} Hz	10^7eV-10^4eV	(a) High penetrating power (b) Uncharged (c) Low ionizing power	(a) Gives information on nuclear structure (b) Medical treatment etc
2.	X-Rays	Roentgen	Due to collisions of high energy electrons with heavy targets	6×10^{-12} m to 10^{-9} m	5×10^{19} Hz to 3×10^{17} Hz	2.4×10^5 eV to 1.2×10^3eV	(a)Low penetrating power (b) other properties similar to γ-rays except wavelength	(a) Medical diagnosis and treatment (b) Study of crystal structure (c) Industrial radiography
3.	Ultraviolet Rays	Ritter	By ionized gases, sun lamp spark etc.	6×10^{-10} m to 3.8×10^{-7} m	3×10^{17} Hz to 5×10^{19} Hz	2×10^3eV to 3eV	(a) All properties of light (b) Photoelectric effect	(a) To detect adulteration, writing and signature (b) Sterlization of water due to its destructive action on bacteria
4.	Visible light Subparts of visible spectrum (a) Violet (b) Blue (c) Green (d) Yellow (e) Orange (f) Red	Newton	Outer orbit electron transitions in atoms, gas discharge tube, incandescent solids and liquids	3.8×10^{-7} m to 7.8×10^{-7} m 3.9×10^{-7} m to 4.55×10^{-7} m 4.55×10^{-7} m to 4.92×10^{-7} m 4.92×10^{-7} m to 5.77×10^{-7} m 5.77×10^{-7} m to 5.97×10^{-7} m 5.97×10^{-7} m to 6.22×10^{-7} m 6.22×10^{-7} m to 7.80×10^{-7} m	8×10^{14} Hz to 4×10^{14} Hz 7.69×10^{14}Hz to 6.59×10^{14}Hz 6.59×10^{14}Hz to 6.10×10^{14}Hz 6.10×10^{14}Hz to 5.20×10^{14}Hz 5.20×10^{14}Hz to 5.03×10^{14}Hz 5.03×10^{14}Hz to 4.82×10^{14}Hz 4.82×10^{14}Hz to 3.84×10^{14}Hz	3.2eV to 1.6eV	(a) Sensitive to human eye	(a)To see objects (b) To study molecular structure

S. No.	Radiation	Discoverer	How produced	Wavelength range	Frequency range	Energy range	Properties	Application
5.	Infra-Red waves	William Herschell	(a) Rearrangement of outer orbital electrons in atoms and molecules. (b) Change of molecular vibrational and rotational energies (c) By bodies at high temperature	7.8×10^{-7} m to 10^{-3} m	4×10^{14}Hz to 3×10^{11}Hz	1.6eV to 10^{-3}eV	(a) Thermal effect (b) All properties similar to those of light except λ	(a) Used in industry, medicine and astronomy (b) Used for fog or haze photography (c) Elucidating molecular structure
6.	Microwaves	Hertz	Special electronic devices such as klystron tube	10^{-3} to 0.3 m	3×10^{11}Hz to 10^{9}Hz	10^{-3} eV to 10^{-5} eV	(a) Phenomena of reflection, refraction and diffraction	(a) Radar and teleco-mmunication. (b) Analysis of fine details of molecular structure
7.	Radio waves Subparts of Radio-spectrum	Marconi	Oscillating circuits	0.3 to few kms	10^{9}Hz to few Hz	10^{-3} eV to ≈ 0	(a) Exhibit waves like properties more than particle like properties	(a) Radio communication
(A) (B)	Super High Frequency (a) SHF Ultra High Frequency (b) UHF Very High Frequency (c) VHF			0.01 m to 0.1 m 0.1 m to 1 m 1 m to 10 m	3×10^{10}Hz to 3×10^{9}Hz 3×10^{9}Hz to 3×10^{8}Hz 3×10^{8}Hz to 3×10^{7}Hz		Radar, Radio and satellite communication (Microwaves), Radar and Television broadcast short distance communication, Television communication.	
	High Frequency (HF) Medium Frequency (MF) Low Frequency (LF) Very Low Frequency (VLF)			10m to 100m 100m to 1000 m 1000 m to 10000 m 10000 m to 30000 m	3×10^{7}Hz to 3×10^{6}Hz 3×10^{6}Hz to 3×10^{5}Hz 3×10^{5}Hz to 3×10^{4}Hz 3×10^{4}Hz to 10^{4}Hz		Medium distance communication Telephone communication, Marine and navigation use, long range communication. Long distance communication	

11 EARTH'S ATMOSPHERE AND ELECTROMAGNETIC WAVES

(i) The gaseous envelop surrounding the earth is called earth's atmosphere.

(ii) It mainly consists of nitrogen 78% and oxygen 21% alongwith a little portion of argon, carbon-di-oxide, water vapour, hydrocarbons, sulphur compounds and dust particles.

(iii) The density of atmospheric air goes on decreasing gradually as we go up.

(iv) The earth's atmosphere has no sharp boundary. However, it has been divided into various regions as given below:

(a) **Troposphere**: It extends upto a height of 12 km from earths surface. The temperature in this region decreases from 298K to 220K and conductivity increases. All climatic changes occur in this region.

(b) **Stratosphre**: It extends from 12 km to 50 km after troposhpere. At the upper part of this region, approximately 20km thick, most of ozone of atmosphere is concentrated. This layer is called as ozone layer. This layer absorbs very large portion of ultraviolet radiations coming from sun, therefore its temperature increases from 220K to 280K.

(c) **Mesosphere**: It extends from 50km to 80 km after stratosphere. In this region the temperature decreases from 280K to 180K

(d) **Ionosphere**: It extends from 80 km to 400 km after mesosphere. The temperature of this region rises from 180K to 700K. In this region ultraviolet radiation coming from sun cause ionisation, therefore this part mostly consists of free electrons and positive ions. The concentration of free electrons is found to be very large in a region beyond 110 km from earth's surface which extends vertically for a few kilometers and is called Kennelly Heaviside layer. Beyond this layer the concentration of free electrons decreases considerably until a height of about 250 km. Beyond it there is another layer of electrons, called Appleton layer.

(v) **Greenhouse effect**: The atmosphere is transparent to visible radiations, but most ifrared (heat) radiations are not allowed to pass through. The energy from the sun heats the earth which then starts emitting radiations like any other hot body. However, since the earth is much colder than sun, its radiations are mainly in the infra red region. These radiations are unable to cross the lower atmosphere and are reflected back. Low lying clouds also reflect back the infra red radiations. As such, the earth's surface warm at night. This phenomenon is called the Green house effect.

(vi) **Propagation of Radio waves**:

(a) **Low frequency waves-the AM band**: Radiowaves having wavelengths of 10m or more (frequency less than 30 Mhz) are said to constitute the AM band. The lower atmosphere is transparent to these waves, but the ionosphere reflects them back. A signal transmitted from a certain point can be received at another point in two possible ways-directly along the surface of the earth (called sky wave) and after reflection from ionosphere (called sky wave). Waves having frequencies upto about 1500kHz (Wavelength above 200m) are mainly transmitted through ground because low frequency sky waves lose their energy very quickly than the sky waves. Therefore, higher frequencies are mainly transmitted through sky. These two regions of the AM band are called medium wave and short wave bands respectively.

(b) **High frequency waves-Television transmission**: Above a frequency of about 40MHz the ionosphere does not reflect the wave toward the earth. The television signals have frequencies in the range 100-200 MHz. Therefore TV transmission via the sky is not possible-only direct reception via the ground is possible. Therefore, in order to have larger coverage, the transmission has to be done through very tall antennas. The height of transmitting antenna for TV telecast is given by $h = \dfrac{d^2}{2R_e}$ where d is the radius of the area to be covered for TV telecast and Re is the radius of earth.

Illustration 8: ***A T.V. tower has a height of 100m. How much population is covered by T.V. broadcast, if the average population density around the tower is 1000/km^2?***

(A) 39.5×10^5 (B) 19.5×10^6
(C) 29.5×10^7 (D) 9×10^4

Solution: (A) Radius of the area covered by T.V. telecast

$d = \sqrt{2hR_e}$

Total population covered $= \pi d^2 \times$ population density

$= 2\pi hR_e \times$ population density

$= 2 \times 3.14 \times 100 \times 6.4 \times 10^6 \times \frac{1000}{10^6}$

$= 39.503 \times 10^5$

Illustration 9: An electromagnetic radiation has an energy 14.4 Kev. To which region of electromagnetic spectrum does it belong?

(A) Infra red region (B) Visible region
(C) X-ray region (D) γ-ray region

Solustion: (C) $\lambda = \frac{hc}{E} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{14.4 \times 10^3 \times 1.6 \times 10^{-19}}$

This wavelength belongs to X-ray region.
Hence the correct answer will be(C)

1. If E and B are the electric and magnetic field vectors of electromagnetic waves then the direction of propagation of electromagnetic wave is along the direction of:
(A) $\vec{E}$ (B) $\vec{B}$ (C) $\vec{E}\times\vec{B}$ (D) None of these
Sol. (C)

2. The charge on a parallel plate capacitor is varying as $q = q_0 \sin 2\pi nt$ The plates are very large and close together. Neglecting the edge effects, the displacement current through the capacitor is:
(A) $\frac{q}{\varepsilon_0 A}$ (B) $\frac{q_0}{\varepsilon_0}\sin 2\pi nt$ (C) $2\pi nq_0 \cos\pi nt$ (D) $\frac{2\pi nq_0}{\varepsilon_0}\cos 2\pi nt$
Sol. (C) $I_D = \frac{dq}{dt} = \frac{d}{dt} q_0\sin 2\pi nt = 2\pi nq_0 \cos 2\pi q_0 \cos 2\pi nt$

3. The value of magnetic field between plates of capacitor, at distance of 1m from centre where electric field varies by 10^{10} V/m/s will be:
(A) 5.56T (B) 5.56μT (C) 5.56mT (D) 55.6nT
Sol. (D) $B = \frac{\mu_0\varepsilon_0 r}{2}\frac{dE}{dt} = \frac{1}{2\times 9\times 10^{16}}\times 10^{10} = 5.56\times 10^{-8}\,T$

4. The electromagnetic waves do not transport:
(A) Energy (B) charge (C) momentum (D) information
Sol. (B)

5. A capacitor is connected in an electric circuit. When key is pressed, the current in the circuit is:
(A) Zero (B) Maximum
(C) any transient value (D) depends on capacitor used
Sol. (B)

6. Displacement current is continuous:
(A) when electric field is changing in the circuit
(B) when magnetic field is changing in the circuit
(C) in both types of fields
(D) through wires and resistance only
Sol. (A)

7. Instantaneous displacement current 1A in the space betwen the parallel plates of 1μF capacitor can be established by chaning the potential difference at the rate of:
(A) 0.1 V/s (B) 1 V/s (C) 10^6 V/s (D) 10^{-6} V/s
Sol. (C) $I_D = \frac{dq}{dt} = C\frac{dv}{dt}$ or $\frac{dv}{dt} = \frac{I_D}{C} = \frac{1}{10^{-6}} = 10^6$ V/s

8. The magnetic field between the plates of a capacitor when r > R is given by:
(A) $\frac{\mu_0 I_D r}{2\pi R^2}$ (B) $\frac{\mu_0 I_D}{2\pi R}$ (C) $\frac{\mu_0 I_D}{2\pi r}$ (D) शून्य
Sol. (C) According to Ampere's law, when $r > R$ $B = \frac{\mu_0 I_D}{2\pi r}$

9. The magnetic field between the plates of a capacitor is given by B = $\frac{\mu_0 Ir}{2\pi R^2}$:

(A) $r \geq R$ (B) $r \leq R$ (C) $r < R$ (D) $r = R$

Sol. (C) According to Ampere's law, when $r > R$ B = $\frac{\mu_0 I_{Dr}}{2\pi R^2}$

10. The conduction current is the same as displacement current when the source is:

(A) A.C. only (B) D.C. only
(C) Both A.C. and D.C. (D) neither for A.C. nor for D.C.

Sol. (B)

11. The wave function (in S.I. units) for an electromagnetic wave is given as:
$\Psi(x, t) = 10^3 \sin\pi (3 \times 10^6 x - 9 - 10^{14} t)$
The speed of the wave as:

(A) 9×10^{14} m/s (B) 3×10^8 m/s
(C) 3×10^{16} m/s (D) 3×10^7 m/s

Sol. (B) $c = \frac{\omega}{k} = \frac{9\times10^{14}}{3\times10^6} = 3 \times 10^8$ m/s

12. In the above problem, wavelength of the wave is:

(A) 666 nm (B) 666 Å (C) 666μm (D) 6.66 nm

Sol. (A) $\Psi(x,t) = 10^3 \sin 3\times10^6 \pi (x - 3 \times 10^8 t)$

Comparing it with

$\Psi(x,t) = a\sin \frac{2\pi}{\lambda}(x - vt)$

$\therefore \frac{2\pi}{\lambda} = 3 \times 10^6\pi$

or $\lambda = \frac{2\times10^9}{3\times10^6} = 666$ nm

13. The Maxwell's four equations are written as:

(i) $\oint \vec{E}.\vec{ds} = \frac{q_0}{\varepsilon_0}$

(ii) $\oint \vec{B}.\vec{ds} = 0$

(iii) $\oint \vec{E}.\vec{dl} = \frac{d}{dt}\oint \vec{B}.\vec{ds}$

(iv) $\oint \vec{B}.\vec{ds} = \mu_0\varepsilon_0 \frac{d}{dt}\oint \vec{E}.\vec{ds}$

The equations which have sources of $\vec{E}$ and $\vec{B}$

(A) (i), (ii), (iii) (B) (i), (ii) (C) (i) and (iii) (D) (i) and (iv)

Sol. (D)

14. Out of the above four equations which do not contain source field are:

(A) (i) and (ii) (B) (ii) only (C) all of four (D) (iii) only

Sol. (B)

15. Out of four Maxwell's equations above, which one shows non-existence of monopoles?

(A) (i) and (iv) (B) (ii) only (C) (iii) only (D) only

Sol. (B)

16. Which of the above Maxwell's equations shows that electric field lines do not form closed loops?

(A) (i) only (B) (ii) only (C) (iii) only (D) (iv) only

Sol. (A)

17. In an electromagnetic wave the average energy density is associated with:

(A) electric field only

(B) magnetic field only

(C) equally with electric and magnetic fields

(D) average energy density is zero

Sol. (C)

18. In an electromagnetic wave the average energy density associated with magnetic field will be:

(A) $\frac{1}{2}LI^2$ (B) $\frac{B^2}{2\mu_0}$ (C) $\frac{1}{2}\mu_0 B^2$ (D) $\frac{1}{2}\frac{q}{B^2}$

Sol. (B)

19. In the above problem, the energy density associated with the electric field will be:

(A) $\frac{1}{2}CV^2$ (B) $\frac{1}{2}\frac{q^2}{C}$ (C) $\frac{1}{2}\frac{\varepsilon^2}{E}$ (D) $\frac{1}{2}\varepsilon_0 E^2$

Sol.: (D)

20. If there were no atmospher, the average temperature on earth surface would be:

(A) Lower (B) Higher (C) same (D) 0°C

Sol. (A) The green house effect would not have been possible without atmosphere. Hence temperature would be lower.

21. In which part of earth's atmosphere is the ozone layer present?

(A) Troposphere (B) Stratosphere (C) Ionosphere (D) Mesosphere

Sol. (B)

22. Kenneley's Heaviside layer lies between:

(A) 50Km to 80 Km (B) 80Km to 400 Km

(C) beyond 110 Km (D) beyond 250 Km

Sol. (C)

23. The ozone layer in earth's atmosphere is crucial for human survival because it:

(A) has ions (B) reflects radio signals

(C) reflects ultraviolet ray (D) reflects infra red rays

Sol. (C)

24. The frequency from 3×10^9 Hz to 3×10^{10} Hz:

(A) High frequency band (B) Super high frequency band

(C) Ultra high frequency band (D) High frequency band

Sol. (B)

25. The frequency from 3 to MHz is known as:

(A) Audio band (B) Medium frequency band

(C) Very high frequency band (D) High frequency band

Sol. (B)

26. The AM range of radiowaves have frequency:
(A) less than 30 MHz (B) More than 30 MHz
(C) less than 20000 Hz (D) More than 20000 Hz

Sol. (A)

27. The displacement current flows in the dielectric of a capacitor
(A) becomes zero (B) has assumed a constant value
(C) is increasing with time (D) is decreasing with time

Sol. (C)

28. Select wrong statement from the following Electromagnetic waves:
(A) are transverse (B) travel with same speed in all media
(C) travel with the speed of light (D) are produced by acceleration charge

Sol. (B)

29. The waves related to tele-communication are:
(A) infra red (B) visible light
(C) microwaves (D) ultraviolet rays

Sol. (C)

30. Electromagnetic waves do not transport:
(A) energy (B) charge
(C) momentum (D) information

Sol. (A)

31. The nature of electromagnetic wave is:
(A) longitudinal (B) longitudinal stationary
(C) transverse (D) transverse stationary

Sol. (C)

32. Greenhouse effect keeps the earth surface:
(A) cold at night (B) dusty and cold
(C) warm at night (D) moist

Sol. (C)

33. A parallel plate capacitor consists of two circular plates each of radius 12 cm and separated by 5.0 mm. The capacitor is being charged by an external source. The charging is being charged and is equal to 0.15 A. The rate of change of potential difference between the plates will be:
(A) 8.173×10^7 V/s (B) 7.817×10^8 V/s
(C) 1.873×10^9 V/s (D) 3.781×10^{10} V/s

Sol. (C) $\frac{dV}{dt} = \frac{I}{C} = \frac{I_d}{\varepsilon_0 A}$

$$= \frac{0.15 \times 5 \times 10^{-3}}{8.85 \times 10^{-12} \times 3.14 \times 0.0144}$$

$= 1.873 \times 10^9$ V/s

34. In the above problem, the displacement current is:
(A) 15A (B) 1.5A (C) 0.15A (D) 0.015A

Sol. (C) $I_D = I_C = 0.15A$

35. The wave emitted by any atom or molecule must have some finite total length which is known as the coherence length. For sodium light, this length is 2.4cm. The number of oscillations in this length will be:
(A) 4.068×10^5 (B) 4.068×10^6 (C) 4.068×10^7 (D) 4.068×10^8

Sol. (B) No. of oscillations in coherence length
$$= \frac{l}{\lambda} = \frac{0.024}{5.9 \times 10^{-7}} = 4.068 \times 10^6 Hz$$

36. In the above problem, the coherence time will be:
(A) $8 \times 10^{-8}s$ (B) $8 \times 10^{-9}s$ (C) $8 \times 10^{-10}s$ (D) $8 \times 10^{-11}s$

Sol. (D) The coherence time $t = \frac{l}{c} = \frac{0.024}{3 \times 10^8} = 8 \times 10^{-11}$ से.

37. A parallel plate capacitor made to circular plates each of radius R = 6cm has capacitance C = 100pF. The capacitance is connected to a 230V A.C. supply with an angular frequency of 300 rad/s. The r.m.s. value of conduction current will be:
(A) 5.7μa (B) 6.3μA (C) 9.6μA (D) 6.9μA

Sol. (D) $I_{RMS} = \frac{E_{RMS}}{X_C} = \omega C E_{RMS}$
$= 300 \times 10^{-10} \times 230 = 6.9\mu A$

38. In the above problem, the displacement current will be:
(A) 6.9μA (B) 9.6μA (C) 6.3μA (D) 5.7μA

Sol. (A) $I_D = I_C = 6.9\mu A$

39. In Q. 37, the value of B at a point 3 cm from the axis between the plates will be:
(A) $1.63 \times 10^{-8}T$ (B) $1.63 \times 10^{-9}T$ (C) $1.63 \times 10^{-10}T$ (D) $1.63 \times 10^{-11}T$

Sol. (D) $B_0 = \frac{\mu_0 (I_D)_{peak} r}{2\pi R^2}$
$$= \frac{2 \times 10^{-7} \times \sqrt{2} \times 6.9 \times 10^{-6}}{2 \times 3.14 \times 36 \times 10^{-4}}$$
$= 1.63 \times 10^{-11}T$

40. A plane electromagnetic wave of frequency 40 MHz travels in free space in the X-direction. At some point and at some instant, the electric field $\vec{E}$ has its maximum value of 750 N/C in Y-direction. The wavelength of the wave is:
(A) 3.5 m (B) 5.5 m (C) 7.5 m (D) 9.5 m

Sol. (C) $\lambda = \frac{C}{f} = \frac{3 \times 10^8}{4 \times 10^7} = 7.5m$

41. In the above problem, the period of the wave will be:
(A) 2.5 μs (B) 0.25 μs (C) 0.025 μs (D) None of these

Sol. (C) $T = \frac{1}{f} = \frac{1}{4 \times 10^7} = 0.025\mu s$

42. In Q. 40, the magnitude and direction of magnetic field will be:
(A) 2.5 μT in X-direction (B) 2.5 μT in Y-direction

(C) 2.5 μT Z-direction (D) none of these

Sol. (C) $B_m = \frac{E_m}{C}\frac{750}{3\times10^8}$ = 2.5μT Z-direction

43. In Q. 40, the angular frequency of e.m.f. wave will be:(in rad/s)
(A) $8\pi \times 10^7$ (B) $4\pi \times 10^6$ (C) $4\pi \times 10^5$ (D) $8\pi \times 10^4$

Sol. (A) $\omega = 2\pi f = 2 \times \pi \times 4 \times 10 = 8\pi \times 10^7$ rad/s.

44. In Q. 40, the propagation constant of the wave will be:
(A) $8.38 m^{-1}$ (B) $0.838 m^{-1}$ (C) $4.19 m^{-1}$ (D) $0.419 m^{-1}$

Sol. (B) $K = \frac{2\pi}{\lambda} = \frac{2\times3.14}{7.5} = 0.838\ m^{-1}$

45. The sun deliverse 10^3 W/m^2 of electromagnetic flux to the earth's surface. The total power that is incident on a roof of dimensions 8m $\times$ 20m, will be:
(A) 6.4×10^3W (B) 3.4×10^4W (C) 1.6×10^5W (D) None of these

Sol. (C) power P = 5A = $10^3 \times 8 \times 20 = 1.6 \times 10^5$W

46. In the above problem, the radiation force on the
(A) 3.33×10^{-5}N (B) 5.33×10^{-4} N (C) 7.33×10^{-3} N (D) None of these

Sol. (B) F = PA = $F = PA = \frac{SA}{c} = \frac{1.6\times10^5}{3\times10^8} = 5.33\times10^{-4}$

47. In Q. 45, the solar energy incident on the roof in 1 hour will be:
(A) 5.76×10^8J (B) 5.76×10^7J (C) 5.76×10^6J (D) 5.76×10^5J

Sol. (A) E = power $\times$ time
$= 1.6 \times 10^5 \times 3600 = 5.76 \times 10^8$J

48. The sun radiates electromagnetic energy at the rate of 3.9×10^{26}W. Its radius is 6.96×10^8m. The intensity of sun light at the solar surface will be:
(A) 1.4×10^4 (B) 2.8×10^5 (C) 4.2×10^6 (D) 5.6×10^7

Sol. (D) $I_{surface} = \frac{P}{A} = \frac{3.9\times10^{26}}{4\times3.14\times(6.96)^2\times10^{16}} = 5.6 \times 10^7$ W/m^2

49. In the above problem, if the distance from the sun to the earth is 1.5×10^{11} m, then the intensity of sunlight on earth's surface will be-(in W/m^2)
(A) 1.38×10^3 (B) 2.76×10^4 (C) 5.52×10^5 (D) इनमें से कोई नहीं

Sol. (A) $I_{earth} = \frac{P}{4\pi r^2} = \frac{3.9\times10^{26}}{4\times3.14\times2.25\times10^{22}} = 1.38 \times 10^3$ W/m^2

50. A laser beam can be focussed on an area equal to the square of its wavelength. A He-Ne laser radiates energy at the rate of 1nW and its wavelength is 632.8 nm. The intensity of focussed beam will be:
(A) 1.5×10^{13} W/m^2 (B) 2.5×10^9 W/m^2
(C) 3.5×10^{17} W/m^2 (D) None of these

Sol. (B) Area through which the energy of beam passes
$= (6.328 \times 10^{-7})^2 = 4 \times 10^{-13}$ m^2
$\therefore I = \frac{P}{A} = \frac{10^{-3}}{4\times10^{-13}} = 2.5 \times 10^9$ W/m^2

51. A flood light is covered with a filter that transmits red light. The electric field of the emerging beam is represented by a sinusoidal plane wave:
$E_x = 36\sin(1.20 \times 10^7 z - 3.6 \times 10^{15} t)$ V/m

The average intensity of the beam will be:

(A) 0.86 W/m^2 (B) 1.72 W/m^2 (C) 3.44 W/m^2 (D) 6.88 W/m^2

Sol. (B) $I_{av} = \frac{c\varepsilon_0 E_0^2}{2} = \frac{3\times10^8\times8.85\times10^{-12}\times36^2}{2}$ = 1.72 W/m^2

52. An electric field of 300 V/m is confined to a circular area 10 cm in diameter. If the field is increasing at the rate of 20 V/m-s, the magnitude of magnetic field at a poit 15cm from the centre of the circle will be:

(A) 1.85×10^{-15} T (B) 1.85×10^{-16} T

(C) 1.85×10^{-17} T (D) 1.85×10^{-18} T

Sol. (D) $B = \frac{\mu_0\varepsilon_0}{2\pi R}\left(\frac{\pi d^2}{4}\right)\frac{dE}{dt}$

$= \frac{2\times10^{-7}\times8.85\times10^{-12}\times3.14\times0.01\times.20}{4\times0.15}$ = 1.85×10^{-18}T

53. A lamp emits monochromatic green light uniformly in all directions. The lamp is 3% efficient in converting electrical power to electromagnetic waves and consumes 100W of power. The amplitude of the electric field associated with the electromagnetic radiation at a distance of 10m from the lamp will be:

(A) 1.34 V/m (B) 2.68 V/m (C) 5.36 V/m (D) 9.37 V/m

Sol. (A) $S_{av} = \frac{P}{4\pi R^2} = \frac{1}{2}\varepsilon_0 c E_0^2$

$\therefore E_0\sqrt{\frac{P}{2\pi R^2\varepsilon_0 c}}$

$= \sqrt{\frac{3}{2\times3.14\times100\times8.85\times10^{-12}\times3\times10^8}}$

= 1.34 V/m

54. A plane electromagnetic wave of wave intensity 6W/m^2 strikes a small mirror of area 40 cm^2, held perpendicular to the approaching wave. The momentum transferred by the wave to the mirror each second will be:

(A) 6.4×10^{-7} kg–m/s (B) 4.8×10^{-8} kg–m/s

(C) 3.2×10^{-9} kg–m/s (D) 1.6×10^{-10} kg–m/s

Sol. (D) In one second

$P = \frac{2U}{c} = \frac{2S_{av}A}{c} = \frac{2\times6\times40\times10^{-4}}{3\times10^8}$

= 1.6×10^{-10} Kg-m/s

55. In the above problem, the radiation force on the mirror will be:

(A) 6.4×10^{-7} N (B) 4.8×10^{-8} N

(C) 3.2×10^{-9} N (D) 1.6×10^{-10} N

Sol. (D) $\therefore$ Momentum per sec is force

$\therefore$ F = 1.6×10^{-10} Newton

56. In the above problem, the wavelength of the wave will be:

(A) 1.5m (B) 66.6m (C) 1.5cm (D) 66.6cm

Sol. (C) Wavelength of electromagnetic wave

$$\lambda = \frac{c}{v} = \frac{3\times10^{8}}{2\times10^{10}} = 1.5\times10^{-2} = 1.5\text{ cm}$$

Hence correct answer will be (C)

57. In Q. 5, the energy density at a distance 3.5m from the source will be_ (in joule/m^3)

(A) 1.73×10^{-5} (B) 1.73×10^{-6} (C) 1.73×10^{-7} (D) 1.73×10^{-8}

Sol. (D) Energy density at 3.5m is given by

$$u = \frac{1}{2}\varepsilon_0 E_m^2$$

$$= \frac{1}{2}\times 8.85\times10^{-12}\times(62.6)^2$$

$= 1.73 \times 10^{-8}$

Hence the correct answer will be(D)

58. A 100 pF capacitor is connected to a 230V, 50 Hz A.C. source. The r.m.s. value of conduction current will be:

(A) 7.2×10^{-6}A (B) 3.6×10^{-5}A (C) 1.8×10^{-4}A (D) 0.9×10^{-3}A

Sol. (A) The r.m.s. value of conduction current

$$I = \frac{V}{Z} = \frac{V}{\frac{1}{2\pi nC}} = 2\pi nCV$$

or $I = 2 \times 3.14 \times 50 \times 100 \times 10^{-12} \times 230$

$= 7.2 \times 10^{-6}$ A

Hence the correct answer will be(A)

59. What should be the height of transmitting antenna if the T.V. telecast is to cover a radius of 128 km?

(A) 1560m (B) 1280m (C) 1050m (D) 79m

Sol. (B) Height of transmitting antenna

$$h = \frac{d^2}{2R_e} = \frac{(128\times10^3)^2}{2\times6.4\times10^6} = 1280\text{m}$$

Hence the correct answer will be(B)

60. The area to be covered for T.V. telecast is doubled, then the height of transmitting antena (T.V. tower) will have to be:

(A) doubled (B) halved (C) quardupled (D) kept unchanged

Sol. (A)The area of transmission surrounding the T.V. tower

$A = \pi d^2 = \pi(2hR_e)$

$A \propto h$

Hence the correct answer will be(A)

Q.1 If $\vec{E}$ and $\vec{B}$ are the electric and magnetic field vectors of electromagnetic waves then the direction of propagation of electromagnetic wave is along the direction of-

(1) $\vec{E}$ (2) $\vec{B}$
(3) $\vec{E}\times\vec{B}$ (4) none of these

Q.2 The electromagnetic waves do not transport-
(1) energy
(2) charge
(3) momentum
(4) information

Q.3 The wave function (in S.I. units) for an electromagnetic wave is given as-
$\Psi(x,t) = 10^3 \sin\pi(3 \times 10^6 x - 9 \times 10^{14} t)$. The speed of the wave is-
(1) 9×10^{14} m/s
(2) 3×10^8 m/s
(3) 3×10^6 m/s
(4) 3×10^7 m/s

Q.4 In the above problem, wavelength of the wave is-
(1) 666 nm (2) 666 Å
(3) 666 μm (4) 6.66 nm

Q.5 In an electromagnetic wave the average energy density is associated with-
(1) electric field only
(2) magnetic field only
(3) equally with electric and magnetic fields
(4) average energy density is zero

Q.6 In an electromagnetic wave the average energy density associated with magnetic field will be-
(1) $\frac{1}{2}LI^2$
(2) $\frac{B^2}{2\mu_0}$
(3) $\frac{1}{2}\mu_0 B^2$
(4) $\frac{1}{2}\frac{\mu_0}{B^2}$

Q.7 In the above problem, the energy density associated with the electric field will be-
(1) $\frac{1}{2}CV^2$
(2) $\frac{1}{2}\frac{q^2}{C}$
(3) $\frac{1}{2}\frac{\varepsilon^2}{E}$
(4) $\frac{1}{2}\varepsilon_0 E^2$

Q.8 In which part of earth's atmosphere is the ozone layer present ?
(1) troposphere

(2) stratosphere
(3) ionosphere
(4) mesosphere

Q.9 The ozone layer is earth's atmosphere is crucial for human survival because it-
(1) hions
(2) reflects radio signals
(3) reflects ultraviolet rays
(4) reflects infra red rays

Q.10 The frequency from 3×10^9 Hz to 3×10^{10} Hz is-
(1) high frequency band
(2) super high frequency band
(3) ultra high frequency band
(4) very high frequency band

Q.11 The frequency from 3 to 30 MHz is known as-
(1) audio band
(2) medium frequency band
(3) very high frequency band
(4) high frequency band

Q.12 The AM range of radiowaves have frequency-
(1) less than 30 MHz
(2) more than 30 MHz
(3) less than 20000 Hz
(4) more than 20000 Hz

Q.13 Select wrong statement from the following for EMW-
(1) are transverse
(2) travel with same speed in all medium
(3) travel with the speed of light
(4) are produced by accelerating charge

Q.14 The waves related to tele-communication are-
(1) infrared
(2) visible light
(3) microwaves
(4) ultraviolet rays

Q.15 The nature of electromagnetic wave is-
(1) longitudinal
(2) longitudinal stationary
(3) transverse
(4) transverse stationary

Q.16 Greenhouse effect keeps the earth surface-
(1) cold at night
(2) dusty and cold
(3) warm at night
(4) moist

Q.17 A plane electromagnetic wave of frequency 40 MHz travels in free space in the X-direction. At some point and at some instant, the electric field $\vec{E}$ has its maximum value of 750 N/C in Y-direction. The wavelength of the wave is-

(1) 3.5 m (2) 5.5 m
(3) 7.5 m (4) 9.5 m

Q.18 In the above problem, the period of the wave will be-

(1) 2.5 μs
(2) 0.25 μs
(3) 0.025 μs
(4) none of these

Q.19 In Q.18, the magnitude and direction of magnetic field will be-

(1) 2.5 μT in X-direction
(2) 2.5 μT in Y-direction
(3) 2.5 μT in Z-direction
(4) none of these

Q.20 In Q.17, the angular frequency of e.m wave will be-(in rad/s)

(1) $8\pi \times 10^7$
(2) $4\pi \times 10^7$
(3) $2\pi \times 10^5$
(4) $\pi \times 10^4$

Q.21 In Q.17, the propagation constant of the wave will be-

(1) 8.38 m^{-1}
(2) 0.838 m^{-1}
(3) 4.19 m^{-1}
(4) 0.419 m^{-1}

Q.22 The sun delivers 10^3 W/m^2 of electromagnetic flux to the earth's surface. The total power that is incident on a roof of dimensions 8m × 20m, will be-

(1) 6.4×10^3 W
(2) 3.4×10^4 W
(3) 1.6×10^5 W
(4) none of these

Q.23 In the above problem, the radiation force on the roof will be-

(1) 3.33×10^{-5} N
(2) 5.33×10^{-4} N
(3) 7.33×10^{-3} N
(4) 9.33×10^{-2} N

Q.24 In Q.22, the solar energy incident on the roof in 1 hour will be-

(1) 5.76×10^8 J
(2) 5.76×10^7 J
(3) 5.76×10^6 J
(4) 5.76×10^5 J

Q.25 The sun radiates electromagnetic energy at the rate of 3.9×10^{26} W. It's radius is 6.96×10^{8} m. The intensity of sun light at the solar surface will be – (in W/m^2)
(1) 1.4×10^4
(2) 2.8×10^5
(3) 4.2×10^6
(4) 5.6×10^7

Q.26 In the above problem, if the distance from the sun to the earth is 1.5×10^{11} m, then the intensity of sunlight on earth's surface will be- (in W/m^2)
(1) 1.38×10^3
(2) 2.76×10^4
(3) 5.52×10^5
(4) none of these

Q.27 The decreasing order of wavelength of infrared, microwave, ultraviolet and gamma rays is :
(1) infrared, microwave, ultraviolet, gamma rays
(2) microwave, infrared, ultraviolet, gamma rays
(3) gamma rays, ultraviolet, infrared, microwaves
(4) microwaves, gamma rays, infrared, ultraviolet

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Q.No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Ans.	3	2	2	1	3	2	4	2	3	2	2	1	2	3	3	3	3	3	3	1
Q.No.	21	22	23	24	25	26	27													
Ans.	2	3	2	1	4	1	2													