15 Electro Magnetic Waves

Gauss's Law for electricity, $\oint_{\text{close surface}} \vec{E} \cdot d\vec{a} = \frac{Q}{\varepsilon_0} = \phi$

Gauss's law for magnetism, $\oint_{\text{close surface}} \vec{B} \cdot d\vec{a} = 0$

The magnetic force line always form closed loops.

Faraday's Law :

$$\text{emf } \varepsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}\left[\oint_{\text{surface}} \vec{B} \cdot d\vec{a}\right]$$

The varying magnetic field generate electric field.

Ampere's circuital Law : $\oint_{\text{line}} \vec{B} \cdot d\vec{l} = \mu_0 I$

$$= \mu_o \int_{\text{surface}} \vec{J} \cdot d\vec{a} \qquad \left(\because I = \vec{J} \cdot d\vec{a}\right)$$

Ampere Maxwell Law :

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 Ic + \mu_0 \varepsilon_0 \int \frac{d\vec{E}}{dt} \cdot d\vec{a}$$

$$= \mu_0 I_c + \mu_0 I_d$$

$$\because \mu_0 I = \mu_0 \left(I_c + I_d\right)$$

Ampere - Maxwell law shows that the total current passing through any surface of which the closed loop is the perimeter is the sum of the, conduction current and the displacement current.

Where $I_c =$ conduction current, $I_d =$ displacement current, I = total current

Displacement current (I_d) :

Displacement current produced due to change of electric field or electric flux with time during the procedure of charging or discharging of capacitor.

- When electric flux linked between two plates of capacitor become constant then displacement current become zero.
- Displacement current and conduction current are equal during charging or discharging of capacitor.

- Magnetic field produced by displacement current like conduction current.
- Unit of displacement current and conduction current is same and is same as 'A' (Ampere)

conduction current $I_c = \int \vec{J} \cdot d\vec{a}$

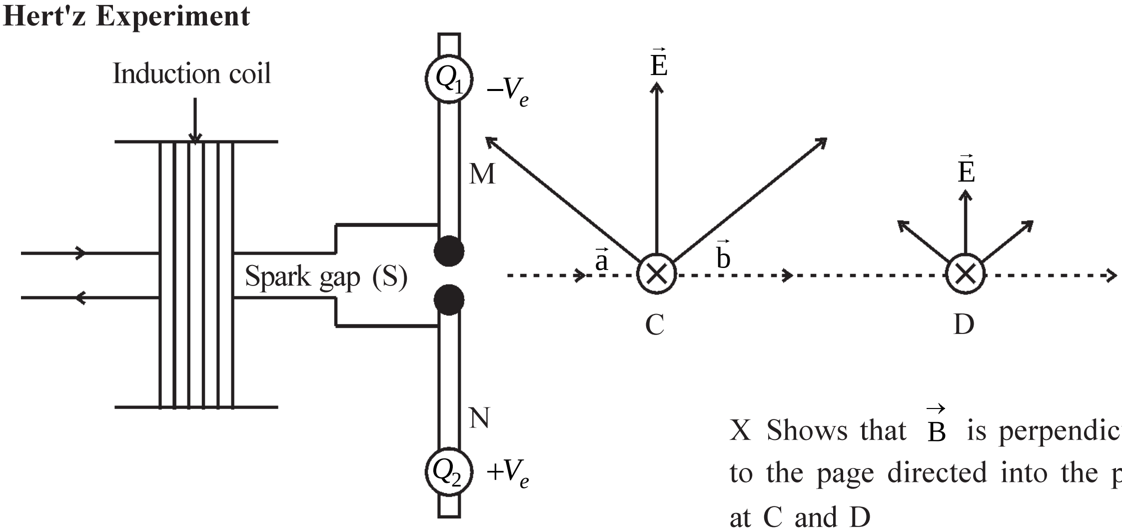
Displacement current $I_d = \varepsilon_0 A \frac{dE}{dt} = \varepsilon_0 \frac{d\phi_E}{dt}$, where $\phi_E = \vec{A} \cdot \vec{E}$

Displacement current in integnal form.

$$I_d = \varepsilon_0 \int \frac{d\vec{E}}{dt} \cdot d\vec{a}$$

Where ε_0 = permittivity of free space and $\frac{dE}{dt}$ = Rate of change of electric field.

Hert'z Experiment



X Shows that $\vec{B}$ is perpendicular to the page directed into the page at C and D

The produced electromagnetic waves travelling along the X direction shown in fig. The spheres Q_1, and Q_2 constitute a capacitor while the rods behave as an inductor. Such an arrangement can be considered equivalent to L-C oscillator circuit and known as Hertzian Dipole. Dipole moment of it is $p = p_0 \cos \omega t$

- The frequency of the generated electromagnetic waves is equal to the frequency of oscillation of the electric changes.
- The energy of the electromagnetic waves is equal to the kinetic energy of the charges oscillating between the two spheres.
- The electric field and magnetic field vectors oscillate in mutually perpendicular planes, perpendicular to the direction of propogation of the waves.
- The direction of propagation is that of $\vec{E} \times \vec{B}$, it's magnitude (in free space) is 3×10^8 ms^{-1}.

(1) The direction of electric field and magnetic field are shown in figure (1) and (2) for a plane electromagnetic wave travelling along X - direction. true option is ......

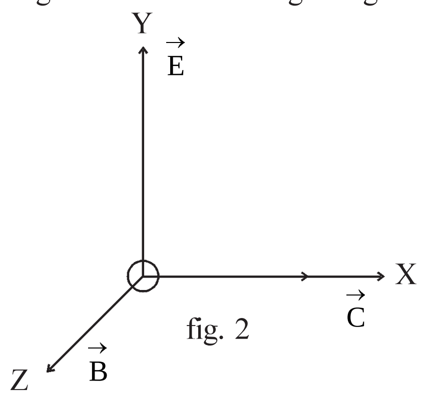


fig. 2

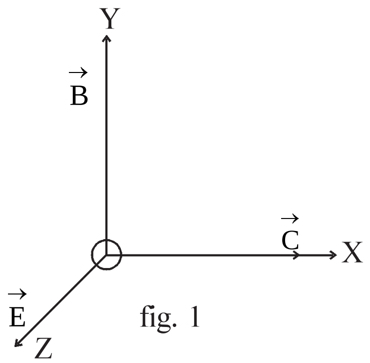


fig. 1

(A) (1) right (2) wrong

(B) (1) and (2) both right

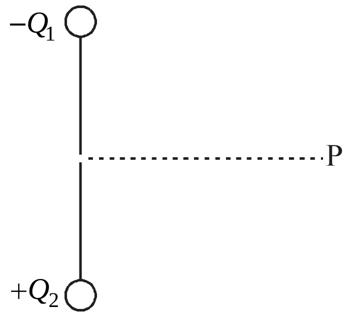
(C) (2) right (1) wrong

(D) (1) and (2) both wrong

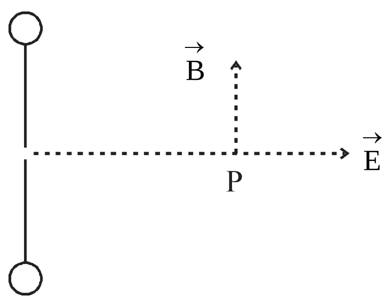
(2) The electric field in Y direction and magnetic field in Z direction for an electromagnetic wave passes in through the space. Which will be true option ?

(A) $\left(\vec{E}\times\vec{B}\right)\bullet\vec{E}=1$ (B) $\left(\vec{E}\times\vec{B}\right)\bullet\vec{B}=1$ (C) $\left(\vec{E}\times\vec{B}\right)\bullet\vec{B}=0$ (D) None of above

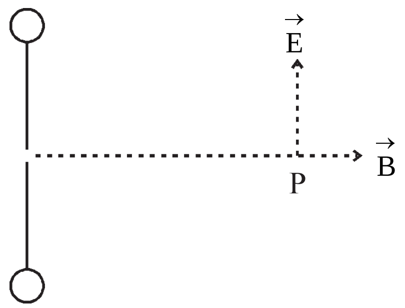
(3) The Hertzian dipole is shown in figure at time t. Which will be the correct option given below for direction of $\vec{E}$ and $\vec{B}$ at point P.



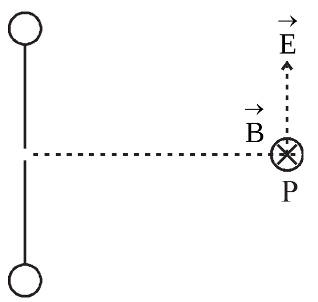
(A)



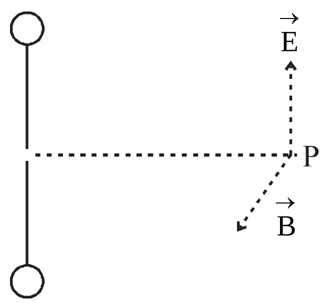
(B)



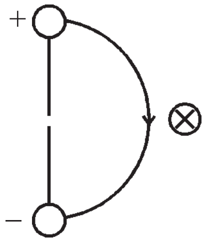
(C)

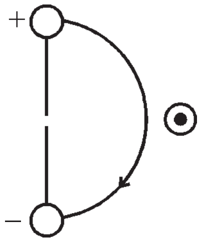


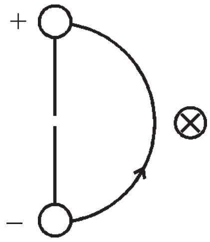
(D)

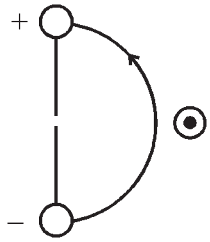


(4) The oscillation of charges of electric dipole shown in figure at time t which one is correct figure of electric field lines and magnetic field line produce due to charges oscillation ?

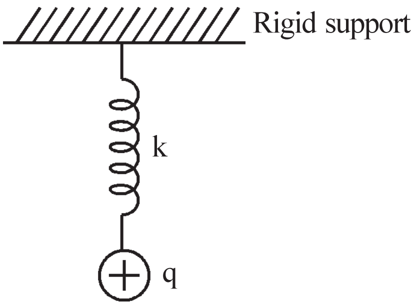
(A)


(B)


(C)


(D)


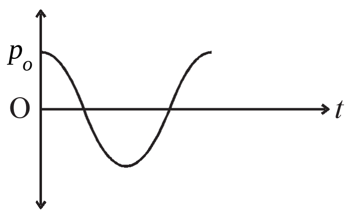
(5) A sphere of mass 5 mg, having charge is hanged at one end of spring of force constant 2×10^{-5} Nm^{-1}. (Shown in figure.) The frequency of emmited radiation will be ________ .

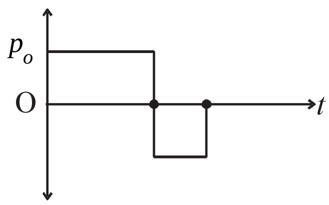


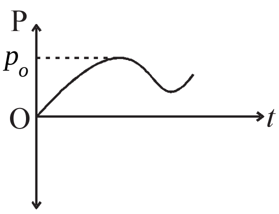
(A) $\frac{1}{2\pi}$ Hz (B) 2π Hz

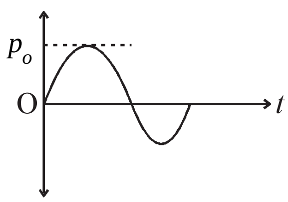
(C) π Hz (D) $\frac{1}{\pi}$ Hz

(6) For Hertzian dipole moment $p = p_o \cos\omega t$ which curve is true from given below, at time $t = \frac{T}{4}, \frac{T}{2}, \frac{3T}{4}$ and T.

(A)


(B)


(C)


(D)


(7) From which is wrong characteristics of electromagnetic waves ?

(A) The maximum and minimum magnitude of electric field and magnetic field vectors produce at same time and same point.

(B) The energy of electromagnetic wave is divide eqully in electric field and magnetic field.

(C) The electric field and magnetic field vectors oscillate in mutually perpendicular and also perpendicular to the direction of propagation of the wave.

(D) Medium is not required for propagation of electromagnetic wave.

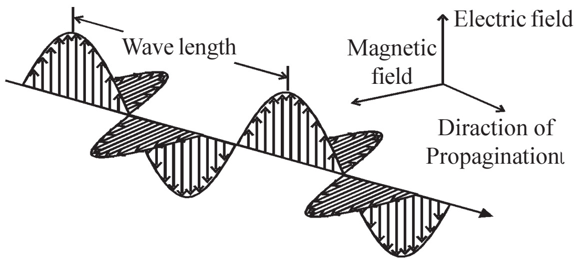
(8) Maxwell's equations indicated the fundamental basic of ________

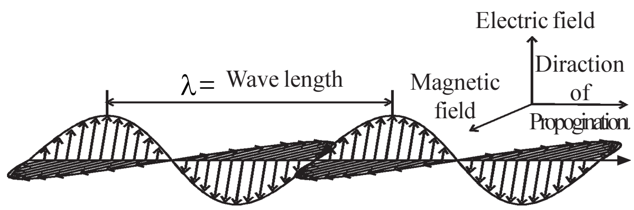
(A) Only charge (B) Only magnet (C) Only mechanics (D) Both (A) and (B)

Ans. : 1 (A), 2 (C), 3 (C), 4 (B), 5 (D), 6 (A), 7 (C), 8 (D)

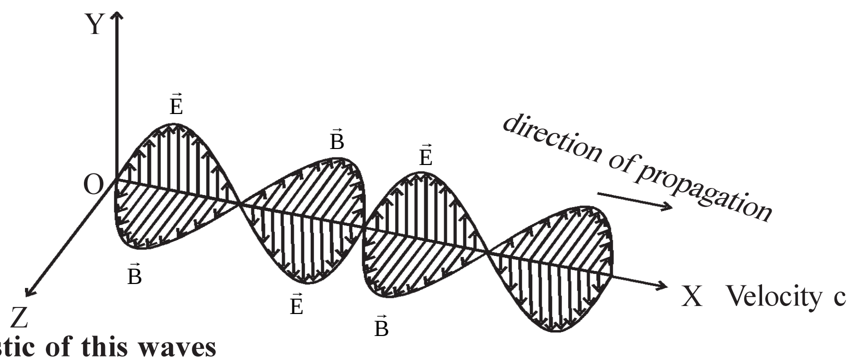
- **Difference between Electromagnetic waves and Plane Electromagnetic Waves**

Electromagnetic Wave	Plane Electromagnetic Wave
• The electric field $(\vec{E})$ and magnetic field $(\vec{B})$ vector osccillate in mutually perpendicular to each other and all possible perpendicular to propagation of direction.	• The electric field $\vec{E}$, and magnetic field $\vec{B}$ vector oscillate in mutually perpendicular plane and perpendicular at propagation of direction along in perticular direction e.g. direction of propagnation in X- axis, $\vec{E}$ vector in Y-axis $\vec{B}$ vector in Z-axis Here, $\frac{dE}{dx} = 0$ and $\frac{dE}{dr} = 0$.
• Unpolarized wave.	• These waves are polarized wave.
• normally near to source area.	• Normally far away from source.
• Cylindaric wave plate	• Wave front are plane
• frequency is not constant	• Constant frequency





- **An Electromagnetic wave propagating along the X-direction**



- **Characteristic of this waves**

  - The equation of an electric field $\vec{E}$ and magnetic field $\vec{B}$ for electromagnetic wave.

Electric field $\vec{E} = E_x \hat{i} + E_y \hat{j} + E_z \hat{k}$ but, $E_x = 0$, $E_z = 0$ and

$E_y = E_o \sin(\omega t - kx)$ so,

$\vec{E} = E_o \sin(\omega t - kx) \hat{j}$

Where $\omega =$ angular frequency and $k =$ wave vector

Magnetic field $\vec{B} = B_x \hat{i} + B_y \hat{j} + B_z \hat{k}$ but $B_x = 0, B_y = 0$ and

$B_z = B_o \sin(\omega t - kx)$ so,

$\vec{B} = B_o \sin(\omega t - kx) \hat{k}$

- **The velocity of electromagnetic wave in vaccum (free space) :**

$$C = \frac{1}{\sqrt{\mu_0 \varepsilon o}}$$

$\mu_0 = 4\pi \times 10^{-7} \text{NA}^{-2}$ = permeability of free space.

$\varepsilon_o = 8.85 \times 10^{-12}\ C^2N^{-1}m^{-2}$ = permittivity of free space.

- **The vector of the electromagnetic waves perpendiculer through away medium :**

$$v = \frac{1}{\sqrt{\mu\varepsilon}} \text{ or } v = \frac{1}{\sqrt{\mu_0\mu_r\varepsilon_o\varepsilon_r}} \text{ or } v = \frac{c}{\sqrt{\mu_r K.}}$$

Where μ = permeability of medium

ε = permittivity of medium

$\mu_r = \dfrac{\mu}{\mu_0}$ = relative permittivity of medium

$\varepsilon_r = \dfrac{\varepsilon}{\varepsilon_0}$ = Relative permeativity of medium

$= K$ = Dielectric constant of the medium

- **The refractive index of the medium :**

$$n = \frac{c}{v} = \sqrt{\mu_1 K} = \sqrt{\mu_r\varepsilon_r}$$

- **Relation between $\vec{E}$ and $\vec{B}$:**

E = cB

  - If electromagnetic wave propagating along positive X direction then $E_y = cB_z$ and its propagating along negative X-direction, Then $E_y = -cB_z$.
  - Direction of vector $\vec{C}$ = Direction of $\left(\vec{E} \times \vec{B}\right)$
  - $\vec{E} = -c\,\hat{c} \times \vec{B}$ and $\vec{B} = \dfrac{\hat{c}}{c} \times \vec{E}$

    Where $\hat{c} = \vec{c}$ unit vector of $\vec{c}$. It's magnitude is $3.0 \times 10^8\ ms^{-1}$

- **The electromagnetic energy per unit volume (energy density) of electromagnetic waves :**
    - Energy density associated with electric field, $\rho_\varepsilon = \frac{1}{2}\varepsilon_o E^2_{rms}$
    - Energy density associated with magnetic field $\rho_B = \frac{B^2_{rms}}{2\mu_0}$
    - Energy density associated with electromagnetic wave.

      $\rho = \varepsilon_o E^2_{rms}$ or $\rho = \frac{B^2_{rms}}{\mu_0}$

- **Intensity of electromagnetic wave :**

Intensity $I = \frac{\text{Energy}}{\text{Time} \times \text{Area}} = \frac{\text{Power}}{\text{Area}}$

$$I = \varepsilon_0 E^2_{rms} \cdot c = \frac{\varepsilon_0 E_0{}^2 c}{2} = \rho c$$

Maximum intensity $I_{max} = E_o B_o$

- **Equation of intensity in form of B_{rms} :**

$$I = \frac{cB^2_{rms}}{\mu_0}$$

$$I = \frac{E_{rms} \cdot B_{rms}}{\mu_0}$$

- **Linear momentum by electromagnetic waves on surface :**

$$P = \frac{U}{c}$$

Where U = The energy of electromagnetic waves incident on a surface and it is completly absorbed.

c = velocity of wave.

If incident energy totally reflect by surface then linear momentum obtain to the surface $P = \frac{2U}{c}$, because change in momentum is $P - (-P) = 2P$.

- **Pointing Vector :**

A power passes through unit area in direction of propagating of wave is called pointing vector $(\vec{S})$.

$$\therefore \quad \vec{S} = \vec{E} \times \vec{H}$$

- Wave impedance : $Z = \frac{E}{H} = \sqrt{\frac{\mu}{\varepsilon}} = \sqrt{\frac{\mu_r \mu_o}{\varepsilon_r \varepsilon_o}}$

  Where $\vec{E} =$ Vector of electric field, $\vec{H} =$ magnetic intensity

- Momentum of wave $P = \frac{\text{Energy}}{\text{Velocity}} = \frac{E}{c}$

- Radiation of pressure $P = \frac{\vec{S}}{c}$

- **Electro magnetic spectrum :**

γ-rays, X-rays, Ultraviolet, Visible, Infrared, Microwave, Short radio wave, long radio wave

frequency f decrease (from γ-rays to radio wave) (value is in decreasing order)

Wave length increases (from γ-rays to radio wave) (value is in ascending order)

- Wave length range, production, detection and uses of different types of electromagnetic waves.

Type	Wavelength Range	Production	Detection	Uses
Radio	> 0.1m	Rapid acceleration and decelerations of electrons in aerials	Receiver's aerials (conducting wire)	Used in radio and TV communication system
Microwave	0.1m to 1 *m*m	Klystron magnetron, Gun diode.	Point contact diodes	Maglev train, RADAR, air craft, navigation, interceptor vans, ovens
Infrared (IR)	1 *m*m to 700 nm	Vibration of atoms and molecules	Thermopile Bolometer, infrared	Infrared lamps are used in physiotheraphy, infrared detectors are used in remote sensing satellites for milletary purpose, agriculture, remote control of TV, video players and wifi systems.
Visible Light	700 nm to 400 nm	Electrons in atom, emit light when they move from one energy level to a lower energy level.	The eye, photocells, photographic film, photo diode, light dependentresistor (LDR)	Used for visibility of objects
Ultraviolet	400 nm to 1 nm	Inner shell electrons in molecule moving from one energy level to a lower level.	Solar cell, Photocells, photographic film	Lasik eye surgery, water purifiers, UV lamps are used to kill germs.
X-*ray*	1 nm to 10^{-3} nm	X-*ray* tubes or inner shell electrons of molecule	Photographic film Geiger tubes, Ionization chamber.	Used in medical applications to find the fracture in bones, as well as in a treatment of certain types of cancer.
Gamma rays	$< 10^{-3}$ nm	Radioactive decay of the nucleus	- do -	Are used in medicine to destroy cancer cells

(9) The electric field of an electromagnetic wave is given by $E = 8.284\left[\left(7.54\times10^{6}\right)\left(t-\frac{x}{3\times10^{8}}\right)\right]$ mVm^{-1}

The energy density field will be ________.

(A) 318.5×10^{-19} J (B) 318.5×10^{-19} Wm^{-3} (C) 318.5×10^{-19} Jm^{-3} (D) 318.5×10^{-19} W

(10) The electric field of an electromagnetic wave with intensity $1.328\ \mathrm{Wm^{-2}}$ is given by $\vec{E} = E_0 \sin\left[\pi\left(9\times10^{14}\,t - 3\times10^{6}\right)\right] i$ Then X component of electric field E_x will be ________

$\left(c = 3\times10^{8}\ \mathrm{ms^{-1}}\right)$, $\left(\varepsilon_0 = 8.85\times10^{-2}\ \mathrm{SI}\right)$

(A) 100 (B) $10\sqrt{10}$ (C) 0.1 (D) 1000

(11) The electric field of an electro magnetic wave is given by $E = 10\sin\left[30\times10^{14}t - 10^{7}x\right]$. Then radiation pressure will be ________.

(A) 4.42×10^{-8} Pa (B) 442 Pa (C) 4.42×10^{-10} Pa (D) 442 $\times 10^{10}$ Pa

(12) Radiation pressure on earth's surface by sunlight of average intensity $1480\ \mathrm{Wm^{-2}}$ is incident on surface of earth is ________ (take $c = 3\times10^{8}\ \mathrm{ms^{-1}}$)

(A) 49.3×10^{6} (B) 49.3×10^{5} (C) 4.93×10^{-6} (D) 4.93×10^{-5}

(13) The permeability of medium having refractive index 1.5 and dielectric is 2, will be ________ TmA^{-1}. $\left(\mu_0 = 4\pi\times10^{-7}\ \mathrm{TmA^{-1}}\right)$

(A) $0.45\,\pi\times10^{-7}$ (B) $5\pi\times10^{-7}$ (C) $5\pi\times10^{-7}$ (D) $4.5\pi\times10^{-7}$

(14) An average intensity of electromagnetic energy is proportional to square of amplitude of wave. In this statement the dimensional formula of proportional constant will be ________ .

(A) $M^{1}\,L^{2}\,T^{-3}\,A^{-1}$ (B) $M^{-1}\,L^{-2}\,T^{3}\,A^{2}$ (C) $M^{1}\,L^{2}\,T^{-3}\,A^{-2}$ (D) $M^{-1}\,L^{-2}\,T^{3}\,A^{1}$

(15) If 50 W radiation energy incident on one surface and it completely absorbed by surface then magnitude of E_{rms} and B_{rms} will be ________ Vm^{-1} and ________ T.

(A) 15.5×10^{-8} (B) 21.7×10^{-8} (C) 18.6×10^{-8} (D) 27.9×10^{-8}

(16) The energy of an electro magnetic waves which are passes through a volume ΔV, associate with this volume, then fregnency of this energy's oscillation is ________ .

(A) zero (B) half the frequency of the wave

(C) the frequency of the wave (D) double the frequency of the wave

(17) The electric field in an em wave is given by $E = 50 \sin\left[\omega\left(t - \frac{x}{c}\right)\right]$. Then the energy contained in a cylinder of cross-section 20 mm^2 and length 50 cm along the X-axis is ________ J.

(A) 4.5×10^{-12} (B) 7.5×10^{-12} (C) 5×10^{-12} (D) 5.5×10^{-12}

(18) The intensity of the sunlight on the earth is $1380\ Wm^{-2}$. Assume this light to be a plane monochromatic wave. Then the amplitude of the magnetic field in the wave is ________ T.

(A) 3.4×10^{-6} (B) 5×10^{-4} (C) 4.2×10^{-6} (D) 2.6×10^{-4}

(19) An em-wave passing through vaccum is described by $E = E_o \sin(kx - \omega t)$. Which of the following is indipendent of the wave length ________ .

(A) $\frac{k}{\omega}$ (B) k (C) ω (D) ωk

(20) If magnetic monopole existed then which of the following Maxwell's equation would be modified ?

(A) $\oint \vec{E} \cdot d\vec{a} = \frac{q_m}{\varepsilon_0}$ (B) $\oint \vec{E} \cdot d\vec{l} = \frac{d}{dt} \int \vec{B} \cdot d\vec{a}$

(C) $\oint \vec{B} \cdot d\vec{a} = 0$ (D) $\mu_0 \omega_o \frac{d}{dt} \int \vec{E} \cdot d\vec{a} + \mu_0 i$

(21) A long straight wire of resistance R, radius a and length l carries a constant current I. The pointing vector for the wire will be ________.

(A) $\frac{IR}{2\pi al}$ (B) $\frac{I^2 R}{al}$ (C) $\frac{IR^2}{al}$ (D) $\frac{I^2 R}{2\pi al}$

(22) Micro waves are used for communication and in RADAR because ________.

(A) They have short wave length (B) Its very less diffraction

(C) Its more diffraction (D) Its propagination with high speed

(23) Give the name of the devices which produced visible light.

(A) Klystrons (B) Magnetrons

(C) Gunn diodes (D) Incondencent lamp

Ans. : 9 (B), 10 (B), 11 (C), 12 (C), 13 (D), 14 (B), 15 (D), 16 (D), 17 (D), 18 (A), 19 (A), 20 (A), 21 (D), 22 (B), 23 (D)

Assertion - Reason type Question :

Instruction : Read assertion and reason carefully, select proper option from given below.

(a) Both assertion and reason are true and reason explains the assertion.

(b) Both assertion and reason are true but reason does not explain the assertion.

(c) Assertion is true but reason is false.

(d) Assertion is false and reason is true.

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(24) **Assertion :** When an electromagnetic wave going through vaccum is described as $E = E_o \sin(kx - \omega t)$, then $\frac{\omega}{k}$ is independent of the wavelength

Reason : $\frac{\omega}{k}$ is speed of the wave.

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

(25) **Assertion :** Displacement current goes through the gap of a capacitor whenever the charge of the capacitor increases or decreases.

Reason : Displacement current $I_d = \mu_0 \frac{d\phi_E}{dt}$

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

(26) **Assertion :** The energy contained in a small volume through which an em wave is passing oscillates with the frequency of the wave.

Reason : Energy density of the wave is given by $\frac{1}{2}\varepsilon_o E^2$

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

Ans. : **24 (a), 25 (a), 26 (D)**

Comprehension Type Questions :

Passage-I :

A light beam travelling in the X-direction is described by the electric field $E_y = 300 \sin\left(\omega t - \frac{x}{c}\right) Vm^{-1}$. An electron is allowed to move along the Y-direction with a speed of $2 \times 10^{-7}\ ms^{-1}$.

(27) The maximum magnetic field is ________.

(A) 9×10^{10} T $-Z$ direction (B) 9×10^{10} T $+Z$ direction

(C) 10^{-6} T $+Z$ direction (D) 10^{-6} T $-Z$ direction

(28) The maximum electric force on the electron is ________ N.

(A) 4.8×10^{-17} (B) 3.6×10^{-17} (C) 2.4×10^{-17} (D) 1.2×10^{-17}

(29) The maximum magnetic force on the electron is ________ N.

(A) 4.8×10^{-18} (B) 3.2×10^{-18} (C) 6.4×10^{-18} (D) 1.6×10^{-18}

Passage-II :

The magnetic field in a plane em wave is given by $B = 200 \sin\left[\left(4 \times 10^{15}\ S^{-1}\right)\left(t = \frac{-x}{c}\right)\right] \mu T$

If $c = 3 \times 10^{8}\ \text{ms}^{-1}$, then answer the following questions :

(30) The maximum electrical field is ________ NC^{-1}.

(A) 2×10^{4} (B) 6×10^{4} (C) 5×10^{4} (D) 3×10^{4}

(31) The average energy is ________ Jm^{-3}.

(A) 18×10^{-3} (B) 21×10^{-3} (C) 24×10^{-3} (D) 16×10^{-3}

(32) Magnitude of pointing vector of electromagnetic wave is ________ $\text{A T}^{-1}\ \text{s}^{-1}$.

(A) 9.55×10^{6} (B) 3.17×10^{6} (C) 4.75×10^{-6} (D) 6.34×10^{6}

Passage-III :

A 2000 W bulb is kept at the centre of a spherical surface at a distance of 20 m from the surface. The working efficiencey of the bulb is 2 % and consider it as point source. Give answer the following question :

$\varepsilon_o = 8.85 \times 10^{-12}$ SI and $c = 3 \times 10^{8}\ \text{ms}^{-1}$

(33) Maximum magnitude of electric field (E_o) for electromagnetic wave is ________ .

(A) 1.73 NC^{-1} (B) 2.45 NC^{-1} (C) 7.96 NC^{-1} (D) 7.13 NC^{-1}

(34) Intensity of electromagnetic wave is ________ Wm^{-2} .

(A) 1.73×10^{-3} (B) 2.45×10^{-3} (C) 7.96×10^{-3} (D) 7.13×10^{-3}

(35) Force acting on surface ________ N .

(A) 7.5×10^{-8} (B) 1.33×10^{-7} (C) 2.65×10^{-7} (D) 2.45×10^{-7}

(36) Density on surface ________ Jm^{-3}.

(A) 1.33×10^{-10} (B) 2.65×10^{-11} (C) 7.50×10^{-8} (D) 2.65×10^{-10}

Ans. : 27 (C), 28 (A), 29 (B), 30 (B), 31 (D), 32 (A), 33 (B), 34 (C), 35 (B), 36 (B)

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