ELECTROMAGNETIC WAVES

STUDY NOTES

- **Displacement current:** It is that current which comes into existence (in addition of conduction current) whenever the electric field and hence, the electric flux changes with time. It is equal to ε_0 times the rate of change electric flux through a given surface.

$$I_D = \varepsilon_0 \frac{d\phi_E}{dt} = \varepsilon_0 A \frac{dE}{dt}$$

- **Modified Ampere circuital law:** It states that the line integral of the magnetic field $\vec{B}$ over a closed path is equal to μ_0 times the sum of conduction current I_c and the displacement current (I_D) threading the closed path.

$$\oint \vec{B}.\vec{dl} = \mu_0 (I_C + I_D)$$

$$= \mu_0 \left(I_c + \varepsilon_0 \frac{d\phi_E}{dt} \right)$$

The sum of conduction and displacement currents has an important property of continuity i.e., the sum remains constant along any closed path.

- **Maxwell's equations:** These are as follows:
  i. Gauss law of electrostatics:

$$\oint \vec{E}.\vec{dS} = \frac{q}{\varepsilon_0}$$

  ii. Gauss law of magnetism:

$$\oint \vec{B}.d\vec{S} = 0$$

  iii. Faraday's law of electromagnetic induction:

$$\oint \vec{E}.\vec{dl} = -\frac{d\phi_B}{dt} = -\frac{d}{dt}\left[\oint \vec{B}.d\vec{S}\right]$$

  iv. Modified Ampere's circuital law:

$$\oint \vec{B}.\vec{dl} = \mu_0 \left[I_c + \varepsilon_0 \frac{d\phi_E}{dt} \right]$$

- **Electromagnetic wave:** An electromagnetic wave is a wave radiated by an accelerated charge and which propagates through space as coupled electric and magnetic fields, oscillating perpendicular to each other and to the direction of propagation of the wave.
- **Principle of production of electromagnetic waves:** An accelerated charge produces electric and magnetic fields, which vary both in space and time. The two oscillating fields act as sources of each other and hence sustain each other. This results in the propagation of an electromagnetic wave through space.
- **Source of an electromagnetic wave:** An accelerating charge produces electromagnetic waves. An electric charge oscillating harmonically with frequency v, generates electromagnetic waves of the same frequency v. An electric dipole is a basic source of electromagnetic waves.

An LC-circuit containing inductance L and capacitance C produces electromagnetic waves of frequency,

$$\nu = \frac{1}{2\pi\sqrt{LC}}$$

- **Mathematical representation of electromagnetic waves**: For a plane electromagnetic wave of frequency ν, wavelength λ, propagating along x-axis, the electric and magnetic fields may be represented as follows:

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

$$= E_0 \sin\left[2\pi\left(\frac{x}{\lambda} - \nu t\right)\right]\hat{j}$$

$$= E_0 \sin\left[2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)\right]\hat{j}$$

and $\vec{B} = B_z\hat{k} = B_0 \sin(kx - \omega t)\hat{k}$

$$= B_0 \sin\left[2\pi\left(\frac{x}{\lambda} - \nu t\right)\right]\hat{k}$$

$$= B_0 \sin\left[2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)\right]\hat{k}$$

Here E_0 and B_0 are the amplitudes of the electric and magnetic fields respectively.

Propagation constant, $K = \frac{2\pi}{\lambda} = \frac{\omega}{c}$

- **Basic properties of electromagnetic waves**

These are

(i) The e.m. waves are produced by accelerated charges and do not require any medium for their propagation.

(ii) The oscillations of $\vec{E}$ and $\vec{B}$ fields are perpendicular to each other as well as to the direction of propagation of the wave. So the e.m. waves are transverse in nature.

(iii) The oscillations of $\vec{E}$ and $\vec{B}$ fields are in same phase.

(iv) All electromagnetic waves travel in free space with same speed given by

$$c = \frac{1}{\sqrt{\mu_0\varepsilon_o}} = 3\times10^8 \text{ ms}^{-1}$$

In a material medium of refractive index μ_r the speed of an electromagnetic wave is given by

$$v = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{c}{\sqrt{\mu_r\varepsilon_r}} = \frac{c}{\mu}$$

(v) The ratio of the amplitudes of electric and magnetic fields is

$$\frac{E_0}{B_0} = c = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$$

(vi) The electromagnetic waves carry energy as they travel through space and this energy is shared equally by the electric and magnetic fields. The average energy of an electromagnetic wave is

$$u = u_E + u_B = \frac{1}{2}\left[\varepsilon_0 E_0^2 + \frac{B_0^2}{\mu}\right]$$

- **Momentum of an electromagnetic wave:** If an electromagnetic wave transfers a total energy U to a surface in time t, then total linear momentum delivered to the surface is, $p = \frac{U}{c}$

- **Intensity of an electromagnetic wave:** The energy crossing per unit area per unit time in a direction perpendicular to the direction of propagation of the wave is called intensity of the wave.

$$\text{Intensity} = \frac{\text{Energy/time}}{\text{Area}} = \frac{\text{Power}}{\text{Area}}$$

For an e.m. wave of average energy density u, I = uc

Also, $I = \frac{1}{2}\varepsilon_0 E_0^2 c = \varepsilon_0 E_{rms}^2 c$

And, $I = \frac{1}{2\mu_0} B_0^2 c = \frac{1}{\mu_0} B_{rms}^2 c$

- **Electromagnetic spectrum:** The orderly distribution of the electromagnetic waves in accordance with their wavelength or frequency into distinct groups having widely differing properties is called electromagnetic spectrum. The main parts of an electromagnetic spectrum in the order of increasing wavelengths from 10^{-2} Å or 10^{-12}m to 10^{-6}m are *Y*-rays, X-rays, ultraviolet rays, visible light, infrared rays, microwaves and radiowaves. The different parts of the e.m. spectrum differ in their methods of production and detection.

QUESTION BANK

MULTIPLE CHOICE QUESTIONS

1. A plane electromagnetic wave of frequency 25GHz is propagating in vacuum along the z-direction. At a particular point in space and time, the magnetic field is given by $\vec{B} = 5\times10^{-8}\,\hat{j}$ T. The corresponding electric field E is (speed of light c $=3\times10^8$ ms^{-1})
   (a) $-15\,\hat{i}$ V/m
   (b) $-1.66 \times 10^{-16}\,\hat{i}$ V/m
   (c) $1.66 \times 10^{-16}\,\hat{i}$ V/m
   (d) $15\,\hat{i}$ V/m
2. A plane electromagnetic wave of frequency 25 MHz travels in free space along the *x*-direction. At a particular point in space and time, $\vec{E} = 6.3\,\hat{j}$V /m. Magnitude of $\vec{B}$ at this point is :
   (a) 2.1×10^{-8} T
   (b) 2.1×10^{-6} T
   (c) 1.1×10^{-8} T
   (d) 4.1×10^{-8} T
3. A plane electromanetic wave is propagating along the direction $\frac{\hat{i}+\hat{j}}{\sqrt{2}}$ with its polarazation along the direction $\hat{k}$. The correct form the magnetic field of the wave would be (here B_0 is an appropriate constant):
   (a) $B_0\frac{(\hat{i}-\hat{j})}{\sqrt{2}}\cos\left(\omega t-k\frac{(\hat{i}-\hat{j})}{\sqrt{2}}\right)$
   (b) $B_0\frac{(\hat{j}-\hat{i})}{\sqrt{2}}\cos\left(\omega t+k\frac{(\hat{i}-\hat{j})}{\sqrt{2}}\right)$
   (c) $B_0\hat{k}\cos\left(\omega t-k\frac{(\hat{i}+\hat{j})}{\sqrt{2}}\right)$
   (d) $B_0\frac{(\hat{i}+\hat{j})}{\sqrt{2}}\cos\left(\omega t-k\frac{(\hat{i}-\hat{j})}{\sqrt{2}}\right)$
4. During the propagation of electromagnetic waves in a medium
   (a) Electric energy density is double of the magnetic energy density
   (b) Electric energy density is half of the magnetic energy density
   (c) Electric energy density is equal to the magnetic energy density
   (d) Both electric and magnetic energy of densities are zero
5. The magnetic field in a travelling electromagnetic wave has a peak value of 20 nT. The peak value of electric field strength is :
   (a) 3 V/m
   (b) 6 V/m
   (c) 9 V/m
   (d) 12 V/m
6. Electromagnetic waves travel in a medium at a speed 2×10^8 ms^{-1}. If the relative permeability of the medium is 1 then the relative permittivity is:
   (a) 2.25
   (b) 1
   (c) 2
   (d) 0.44

7. The ratio of contributions made by the electric field and magnetic field components to the intensity of an electromagnetic wave is : (c = speed of electromagnetic waves)

(a) 1 : 1 (b) 1 : c (c) 1 : c^2 (d) c : 1

8. An EM wave is propagating in a medium with a velocity $\vec{v} = v\hat{i}$. The instantaneous oscillating electric field of this em wave is along $+y$ axis. Then the direction of oscillating magnetic field of the EM wave will be along

(a) –z direction (b) +z direction (c) $-y$ direction (d) $-x$ direction

9. Which colour of the light has the longest wavelength?

(a) Blue (b) Violet (c) Red (d) Green

10. In an electromagnetic wave in free space that root mean square value of the electric field is $E_{rms} = 6\ V\ m^{-1}$. The peak value of the magnetic field is

(a) 2.83×10^{-8} T (b) 0.70×10^{-8} T

(c) 4.23×10^{-8} T (d) 1.41×10^{-8} T

11. Electric field in a plane electromagnetic wave is given by $E = 50 \sin (500x - 10 \times 10^{10} t)$ V/m. The velocity of electromagnetic wave in this medium is :

(Given c = speed of light in vacuum)

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

12. The electric field of a plane electromagnetic wave propagating along the X direction in vacuum is $\vec{E} = \vec{E}_0 j \cos(\omega t - kx)$. The magnetic field $\vec{B}$, at the moment $t = 0$ is

(a) $\vec{B} = \frac{E_0}{\sqrt{\mu_0 \varepsilon_0}} \cos(kx)\hat{j}$ (b) $\vec{B} = \frac{E_0}{\sqrt{\mu_0 \varepsilon_0}} \cos(kx)\hat{k}$

(c) $\vec{B} = E_o\sqrt{\mu_0 \varepsilon_0} \cos(kx)\hat{k}$ (d) $\vec{B} = E_o\sqrt{\mu_0 \varepsilon_0} \cos(kx)\ \hat{j}$

13. Out of the following options which one can be used to produce a propagating electromagnetic wave?

(a) A chargeless particle (b) An accelerating charge

(c) A charge moving at constant velocity (d) A stationary charge

14. A 1000Ω resistance and a capacitor of 100 Ω resistance are connected in series a 220 V source, when the capacitor is 50% charged, the value of the displacement current is

(a) $11\sqrt{2}$ A (b) 2.2 A (c) 11 A (d) 4.4 A

15. **Assertion :** When variable frequency a.c. source is connected to a capacitor, displacement current increases with increase in frequency.

Reason : As frequency increases conduction current also increases.

(a) Both Assertion and Reason are correct and Reason is the correct explanation for Assertion

(b) Both Assertion and Reason are correct but Reason is not the correct explanation for Assertion

(c) Assertion is correct but Reason is incorrect

(d) Both Assertion and Reason are incorrect

16. A parallel beam of light is incident normally on a plane surface absorbing 40% of the light and reflecting the rest. If the incident beam carries 60 watt of power, the force exerted by it on the surface is:

(a) 3.2×10^{-8} N (b) 3.2×10^{-7} N

(c) 5.2×10^{-7} N (d) 5.12×10^{-8} N

17. The electric field part of an electromagnetic wave in a medium is represented by $E_x = 0$;

$$E_y = 2.5\frac{N}{C}\cos\left[\left(2\pi \times 10^6 \frac{rad}{2}\right)t - \left(\pi \times 10^{-2}\frac{rad}{m}\right)x\right].$$

$E_z = 0$. The wave is :

(a) Moving along x direction with frequency $2\pi \times 10^6$ Hz and wavelength 200 m.
(b) Moving along y direction with frequency $2\pi \times 10^6$ Hz and wavelength 200 m.
(c) Moving along x direction with frequency 10^6 Hz and wavelength 100 m.
(d) Moving along x direction with frequency 10^6 Hz and wavelength 200 m.

18. The conduction current is same as displacement current when source is
(a) a.c. only (b) d.c. only
(c) both a.c. and d.c. (d) neither for d.c. nor for a.c.

19. A plane electromagnetic wave, has frequency of 2.0×10^{10} Hz and its energy density is 1.02×10^{-8} J/m^3 in vacuum. The amplitude of the magnetic field of the wave is close to ($\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \frac{Nm^2}{C^2}$ and speed of light $= 3\times10^8 ms^{-1}$)
(a) 190 nT (b) 150 nT (c) 160 nT (d) 180 nT

20. A parallel plate capacitor is charged by a current of 2×10^{-7} A is displaced between the plates of capacitor. When discharge of the capacitor takes place through a resistance, the rate of change of electric flux (in Wb/s) will be
(a) 2.26×10^4 (b) 4.26×10^8 (c) 3.26×10^6 (d) 6.26×10^9

21. A radio wave of frequency 90 MHz (FM) enter into a ferrite rod. If $\varepsilon_r = 10^3$ and $\mu_r = 10$, then the velocity and wavelength of radiowave in ferrite rode is:
(a) $3\times10^6 ms^{-1}$, 3.33×10^{-2}m (b) $3\times10^5 ms^{-1}$, 3.33×10^{-1}m
(c) $3\times10^6 ms^{-1}$, 3.33×10^{-3}m (d) $3\times10^5 ms^{-1}$, 3.33×10^{-2}m

22. Light can travel in vacuum due to its
(a) transverse nature (b) electromagnetic nature
(c) longitudinal nature (d) both (a) and (c).

23. Which of the following has minimum wavelength?
(a) X-ray (b) γ- ray (c) Ultraviolet ray (d) Cosmic ray

24. Electromagnetic waves travel in a medium which has relative permeability 1.3 and relative permittivity 2.14. Then the speed of the EM wave in the medium will be
(a) 13.6×10^6 m/s (b) 1.8×10^2 m/s (c) 3.6×10^8 m/s (d) 1.8×10^8 m/s

25. For a medium with permittivity ε and permeability μ, the velocity of light is given by
(a) $\sqrt{\frac{\mu}{\varepsilon}}$ (b) $\sqrt{\mu\varepsilon}$ (c) $1/\sqrt{\mu\varepsilon}$ (d) $\sqrt{\frac{\varepsilon}{\mu}}$

26. Electromagnetic waves are transverse in nature is evident by
(a) polarization (b) interference (c) reflection (d) diffraction

27. Infrared radiations are detected by
(a) spectrometer (b) pyrometer (c) nanometre (d) photometer

28. The dimensions of $\frac{1}{2}\varepsilon_0 E^2$ is
(a) MLT^{-1} (b) ML^2T^{-2} (c) $ML^{-1}T^{-2}$ (d) ML^2T^{-1}

29. An electromagnetic wave of frequency 3 MHz passes from vacuum into a dielectric medium with permittivity $\varepsilon = 4$. Then,
(a) Wavelength and frequency both remain unchanged.
(b) Wavelength is doubled and the frequency remains unchanged.
(c) Wavelength is doubled and the frequency becomes half.
(d) Wavelength is halved and the frequency remains unchanged.

30. A small metallic ball is charged positively and negatively in a sinusoidal manner at frequency of 10^6 cps. The maximum charge on the ball is 10^{-6} C. What is the displacement current due to this alternating current ?
(a) 6.28 amp (b) 3.8 amp (c) 3.75×10^{-4} amp (d) 122.56 amp

31. In an electromagnetic wave, the electric and magnetic fields are 100 V/m and 0.265 A/m. The maximum energy flow will be

(a) 79 W/m^2 (b) 13.2 W/m^2 (c) 53.0 W/m^2 (d) 26.5 W/m^2

32. If a source is transmitting electromagnetic waves of frequency 8.2×10^6 Hz the wavelength of electromagnetic wave transmitted from the source is

(a) 35.6 m (b) 18.8 m (c) 42.8 m (d) 58 m

33. The decreasing order of wavelength of infrared, microwave, ultraviolet and gamma rays is

(a) microwave, infrared, ultraviolet, gamma rays
(b) gamma rays, ultraviolet, infrared, microwave
(c) microwave, gamma rays, infrared ultraviolet
(d) infrared, microwave, ultraviolet, gamma rays

34. The electric and the magnetic fields, associated with an em wave, propagating along the + z-axis, wave in a medium is represented by

(a) $[\vec{E} = \vec{E}_0\hat{j}\,;\ \vec{B} = B_0\hat{k}]$ (b) $[\vec{E} = \vec{E}_0\hat{i}\,;\ \vec{B} = B_0\hat{j}\,]$
(c) $[\vec{E} = \vec{E}_0\hat{k}\,;\ \vec{B} = B_0\hat{i}]$ (d) $[\vec{E} = \vec{E}_0\hat{j}\,;\ \vec{B} = B_0\hat{i}]$

35. The electric field in an e.m. wave is given by $E = 50 \sin\frac{2\pi}{\lambda}(ct-x)\ NC^{-1}$. The energy contained in a cylinder of cross section 10 cm^2 and length 50 cm along the x – axis is :

(a) 55 J (b) 5.5×10^{-12} J (c) 5.5×10^{-11} J (d) 55×10^{-12} J

36. A beam has intensity $2.5 \times 10^{14}\ Wm^{-2}$, the amplitude of magnetic field in the beam is

(a) 144 T (b) 1.44 T (c) 14.4 T (d) 4.3 T

37. For e.m. wave propagating along x-axis, E_{max} =30 V/m. What is maximum value of magnetic field?

(a) 10^{-7} T (b) 10^{-8} T (c) 10^{-9} T (d) 10^{-6} T

38. Which of the following is used to produce radio waves of constant amplitude?

(a) Oscillator (b) FET (c) Rectifier (d) Amplifier

39. If an electron oscillates at a frequency of 1GHz it gives

(a) X-rays (b) microwaves (c) infrared rays (d) none of these

40. If the frequency of oscillating particle is *n* then the frequency of oscillation of its potential energy is

(a) n (b) $2n$ (c) $n/2$ (d) $4n$

41. When high energy UV photon beam enters an electric field, it will be

(a) accelerated (b) retarded (c) undeflected (d) none of these

42. A plane e.m. wave of frequency 30 MHz travels in free space along the x-direction. The electric field component of the wave at a particular point of space and time is $E = 6Vm^{-1}$ along y-direction. Its magnetic field component B at this point would be

(a) 2×10^{-8} T along z-direction (b) 6×10^{-8} T along x-direction
(c) 2×10^{-8} T along y-direction (d) 6×10^{-8} T along z-direction

43. An EM wave of intensity I falls on a surface kept in vacuum and exerts radiation pressure p on it. Which of the following is not true?

(a) Radiation pressure $\frac{1}{c}$ is if the wave is totally absorbed C

(b) Radiation pressure $\frac{1}{c}$ is if the wave is totally reflected

(c) Radiation pressure is $\frac{2I}{c}$ if the wave is totally reflected

(d) Radiation pressure is in the range $\frac{1}{c} < p < \frac{2I}{c}$ for real surfaces

44. One requires 11 eV of energy to dissociate a carbon monoxide molecule into carbon and oxygen atoms. The minimum frequency of the appropriate electromagnetic radiation to achieve the dissociation lies in

(a) visible region (b) infrared region

(c) ultraviolet region (d) microwave region

45. Choose the correct answer from the alternative given.

A parallel plate capacitor with plate area A and separation between the plates d is charged by a constant current I. Consider a plane surface of area A/2 parallel to the plate and drawn between the plates. The displacement current through the area is :

(a) I (b) $\frac{I}{2}$ (c) $\frac{I}{4}$ (d) $\frac{I}{8}$

46. Light with a energy flux of 20 W/cm^2 falls on a non reflecting surface at normal incidence. If the surface has an area of 30 cm^2, the total momentum delivered for complete absorption during 30 min is

(a) 36×10^{-5} kg–m/s (b) 36×10^{-4} kg–m/s

(c) 108×10^{4} kg–m/s (d) 1.08×10^{7} kg–m/s

47. The electric field intensity produced by the radiations coming from 100 W bulb at a 3 m distance is E. The electric field intensity produced by the radiations coming from 50 W bulb at the same distance is

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

48. An EM wave radiates outwards from a dipole antenna, with E_0 as the amplitude of its electric field vector. The electric field E_0 transports significant energy from the source falls of as

(a) $\frac{1}{r^3}$ (b) $\frac{1}{r^2}$ (c) $1/r$ (d) remains constant

49. If E and B represents electric and magnetic field vector of the electromagnetic wave, the direction of propagation of electromagnetic wave is along

(a) E (b) B (c) B × E (d) E × B

50. The velocity of an electromagnetic wave in vacuum can be changed by changing

(a) frequency (b) amplitude (c) wavelength (d) none of these

51. What will be the amplitude of magnetic field in a parallel beam of light of intensity 4.0 W/m^2?

(a) 1.83×10^{-7} (b) 1.83×10^{-6} (c) 18.3×10^{-7} (d) 18.3×10^{-6}

52. Suppose that the electric field amplitude of an electromagnetic wave is E_0=120 N/C and that frequency is f = 50 MHz, then k is :

(a) 1.05 m (b) 0.05 m^{-1} (c) 1.05 m^{-1} (d) insufficient data

53. The part of the spectrum of the electromagnetic radiation used to cook food is

(a) ultraviolet rays (b) cosmic rays (c) X-rays (d) microwaves

54. The rate of loss of heat of a body is directly proportional to the difference of temperature of the body and the surroundings. This statement is known as

(a) Stefan's law (b) Newton's law of cooling

(c) Wien's law (d) Kirchhoff's law

55. An electromagnetic wave going through vacuum is described by

$E = E_0 \sin (kx-\omega t)$, $B = B_0 \sin (kx-\omega t)$. Which of the following equations is true?

(a) $E_0 k = B_0\omega$ (b) $E_0\omega = B_0 k$ (c) $E_0B_0 = \omega k$ (d) None of these

56. A source emits electromagnetic waves of wavelength 3 m. One beam reaches the observer directly and other after reflection from a water surface, travelling 1.5 m distance and with intensity reduced to (1/4) as compared to intensity due to direct beam alone. The resultant intensity will be

(a) (1/4) fold (b) (3/4) fold (c) (5/4) fold (d) (9/4) fold

57. The essential distinction between X-rays and γ-rays is that

(a) γ-rays have smaller wavelength than X-rays

(b) γ-rays emanate from nucleus while X-rays emanate from outer part of the atom
(c) γ-rays have greater ionizing power than X
(d) y-rays are more penetrating than X-rays

58. The speed of electromagnetic wave in vacuum depends upon the source of radiation
(a) increases as we move from γ-rays to radio waves
(b) decreases as we move from γ-rays to radio waves
(c) is same for all of them
(d) None of the above

59. In a free space electron is placed in the path of a plane electromagnetic wave, it will start moving along
(a) centre of earth (b) equator of earth (c) magnetic field (d) electric field

60. The average magnetic energy density of an electromagnetic wave of wavelength λ travelling in free space is given by
(a) $\frac{B^2}{2\lambda}$ (b) $\frac{B^2}{2\mu_0}$ (c) $\frac{2B^2}{\mu_0\lambda}$ (d) $\frac{B}{\mu_0\lambda}$

61. The magnetic field in a plane electromagnetic wave is given by $2\times10^{-7}\sin(0.5\times10^3x + 1.5\times10^{11}t)$. The electromagnetic wave is
(a) Visible light (b) Infrared (c) Microwave (d) Radiowave

62. Which of the following shows greenhouse effect?
(a) Ultraviolet rays (b) Infrared rays (c) X-rays (d) None of these

63. A plane electromagnetic wave propagation in the x-direction has a wavelength of 5.0 mm. The electric field is in the y-direction and its maximum magnitude is 30V/m. Find equation for the electric field as a field as a function of x and t.
(a) $E = 30\sin[12\pi \times 10^{10}t - 400\pi x]$ (b) $E = 15\sin[400\pi \times -12\pi \times 10^{10}]$
(c) $E = 30\sin[48\pi \times 10^{10}t - 1200\pi x]$ (d) $E = 15\sin[48\pi \times 10^{10}t - 1200\pi x]$

64. Which one of the following is the property of a monochromatic, plane electromagnetic waves in free space?
(a) Electric and magnetic fields have a phase difference of $\pi/2$
(b) The energy contribution of both electric and magnetic fields are equal
(c) The direction of propagation is in the direction of $B \times E$
(d) The pressure exerted by the wave is the product of its speed and energy density

65. The sun delivers 10^4 W/m^2 of electromagnetic flux to earth's surface. The total power that is incident on a roof of dimensions (10×10) m^2 will be
(a) 10^4 W (b) 10^5 W (c) 10^6 W (d) 10^7 W

66. Which of the following does not represent Maxwell equation?
(a) $\oint\vec{E}.d\vec{A} = \frac{q}{\varepsilon_0}$ (b) $\oint\vec{B}..d\vec{A} = 0$
(c) $\oint\vec{E}.d\vec{A} = \frac{-dB}{dt}$ (d) $\oint\vec{B}..d\vec{l} = \mu_0 I_c + \mu_0\varepsilon_0\frac{d\phi_E}{dt}$

67. A parallel plate capacitor consists of circular plates with radius 10 cm, separated by a distance of 0.5 mm. The capacitor is charged by an external source such that the electric field between the plate changes at rate 5×10^{13}V m^{-1} s^{-1}. The displacement current through the capacitor is
(a) 1.4 mA (b) 14 mA (c) 14 A (d) 1.4 A

68. A standing em wave frequency 2.2×10^{10} Hz is produced in a certain material nodal planes of magnetic field are 3.5 mm apart. Find speed of the wave in this material.
(a) 2.81×10^8 ms^{-1} (b) 1.79×10^8 ms^{-1} (c) 3.08×10^8 ms^{-1} (d) 1.54×10^8 ms^{-1}

69. The Sun delivers 10^3 W/m^2 of electromagnetic flux to the Earth's surface. The radiation force on the roof of dimensions 8m $\times$ 20 m will be :
(a) 3.33×10^{-5} N (b) 5.33×10^{-4} N (c) 7.33×10^{-3} N (d) 9.33×10^{-2} N

70. 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

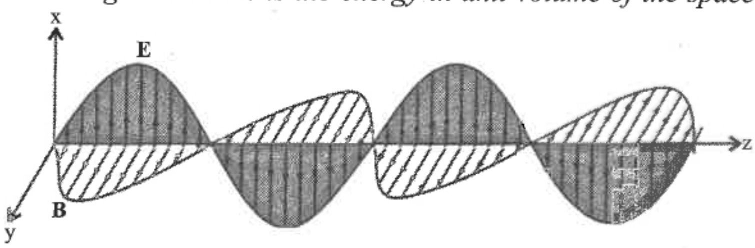
71. Choose the correct answer from the alternatives given.

Displacement current goes through the gap between the plates of a capacitor when the charge of the capacitor

(a) increases
(b) decreases
(c) increases or decreases
(d) is zero

INPUT TEXT BASED MCQs

1. *It can be shown from Maxwell's equations that electric and magnetic fields in an electromagnetic wave are perpendicular to each other, and to the direction of propagation. In Figure below we show a typical example of a plane electromagnetic wave propagating along the z direction (the fields are shown as a function of the z coordinate, at a given time t). The electric field E_x is along the x-axis, and varies sinusoidally with z, at a given time. The magnetic field B_y is along the y-axis, and again varies sinusoidally with z. The electric and magnetic fields E_x and B_y are perpendicular to each other, and to the direction z of propagation. Electromagnetic waves carry energy as they travel through space and this energy is equally shared by the electric and magnetic fields. Energy density of an electromagnetic waves is the energy in unit volume of the space through which wave travels.*



(i) The EM waves propagated perpendicular to both $\vec{E}$ and $\vec{B}$. The electromagnetic waves travel in the direction of

(a) $\vec{E}\cdot\vec{B}$ (b) $\vec{E} \times \vec{B}$ (c) $\vec{B}\cdot\vec{E}$ (d) $\vec{B} \times \vec{E}$

(ii) What is the fundamental particle of electromagnetic waves?

(a) Photon (b) Electron (c) Phonon (d) Proton

(iii) For a wave propagating in a medium, identify the property that is independent of the others?

(a) Velocity
(b) Wavelength
(c) Frequency
(d) All these depend on each other

(iv) What property gives evidence that em waves are transverse in nature?

(a) Polarization (b) Interference (c) Reflection (d) Diffraction

(v) The electric and magnetic fields of an electromagnetic waves are

(a) in opposite phase and perpendicular to each other
(b) in opposite phase and parallel to each other
(c) in phase and perpendicular to each other
(d) in phase and parallel to each other.

2. *An electromagnetic wave (like other waves) carries energy and momentum. Since it carries momentum, an electromagnetic wave also exerts pressure, called radiation pressure. If the total energy transferred to a surface in time t is U, it can be shown that the magnitude of the total momentum delivered to this surface (for complete absorption) is,* $p = \frac{U}{c}$. *In 1903, the American scientists Nicols and Hull succeeded in measuring radiation pressure of visible light and verified then above relation. It was found to be of the order of* 7×10^{-6} N/m^2. *Thus, on a surface of area* 10 cm^2, *the force due to radiation is only about* 7×10^{-9} *N.*

(i) Light with an energy flux of 18 W/cm^2 falls on a non reflecting surface at normal incidence. If the surface has an area of 20 cm^2, then the average force exerted on the surface during a 30 minute time span is

(a) 1.2×10^{-6} N (b) 7×10^{-9} N. (c) 2.16×10^{-9} N. (d) 7×10^{-6} N.

(ii) The pressure exerted by an electromagnetic wave of intensity I (Wm^{-2}) on a non-reflecting surface is (c is the velocity of light)

(a) Ic (b) Ic^2 (c) I/c (d) I/c^2

(iii) Light with an energy flux of 18 W/cm^2 falls on a non-reflecting surface at normal incidence. The pressure exerted on the surface is

(a) 2 N/m^2 (b) 2×10^{-4} N / m^2 (c) 6 N/m^2 (d) 6×10^{-4} N /m^2

(iv) Radiation of intensity 0.5 W m^{-2} are striking a metal plate. The pressure on the plate is

(a) 0.166×10^{-8} Nm^{-2} (b) 0.212×10^{-8} Nm^{-2} (c) $0.132\times10^{+2}$ Nm^{-2} (d) 0.083×10^{-8} Nm^{-2}

(v) A point source of electromagnetic radiation has an average power output of 1500 W. The maximum value of electric field at a distance of 3 m from this source (in V m^{-1})

(a) 500 (b) 100 (c) 500/3 (d) 250/3

ANSWERS

1. (d)	**2.** (a)	**3.** (a)	**4.** (a)	**5.** (b)	**6.** (a)	**7.** (a)	**8.** (b)	**9.** (c)	**10.** (a)
11. (c)	**12.** (c)	**13.** (b)	**14.** (b)	**15.** (a)	**16.** (b)	**17.** (d)	**18.** (a)	**19.** (c)	**20.** (a)
21. (a)	**22.** (b)	**23.** (b)	**24.** (d)	**25.** (c)	**26.** (a)	**27.** (b)	**28.** (c)	**29.** (d)	**30.** (a)
31. (d)	**32.** (a)	**33.** (a)	**34.** (b)	**35.** (b)	**36.** (b)	**37.** (a)	**38.** (a)	**39.** (d)	**40.** (b)
41. (c)	**42.** (a)	**43.** (b)	**44.** (c)	**45.** (b)	**46.** (b)	**47.** (a)	**48.** (c)	**49.** (d)	**50.** (d)
51. (a)	**52.** (c)	**53.** (a)	**54.** (b)	**55.** (a)	**56.** (d)	**57.** (b)	**58.** (c)	**59.** (d)	**60.** (b)
61. (c)	**62.** (b)	**63.** (a)	**64.** (b)	**65.** (c)	**66.** (c)	**67.** (c)	**68.** (d)	**69.** (b)	**70.** (a)
71. (c)									

Input Text Based MCQs

1. (i) (b), (ii) (a), (iii) (c), (iv) (a), (v) (c) **2.** (i) (a), (ii) (c), (iii) (d), (iv) (a), (v) (b)