ELECTROMAGNETIC WAVES

MULTIPLE CHOICE QUESTIONS

1. An electromagnetic wave can be produced, when charge is
   (A) moving with a constant velocity
   (B) moving in a circular orbit
   (C) falling in an electric field
   (D) both B and C

2. If E and B denote electric and magnetic fields respectively, which of the following is dimensionless?
   (A) $\sqrt{\mu_0\varepsilon_0}\frac{E}{B}$ (B) $\mu_0\varepsilon_0\frac{E}{B}$
   (C) $\mu_0\varepsilon_0\left(\frac{B}{E}\right)^2$ (D) $\frac{E}{\varepsilon_0}\frac{\mu_0}{B}$

3. The electric field of an electromagnetic wave travelling through vacuum is given by the equation $E = E_0\sin(kx - \omega t)$. The quantity that is independent of wavelength is
   (A) $k\omega$ (B) $\frac{k}{\omega}$
   (C) $k^2\omega$ (D) ω

4. Radiations of intensity 0.5 W m^{-2} are striking a metal plate. The pressure on the plate is
   (A) 0.166×10^{-8} N m^{-2} (B) 0.332×10^{-8} N m^{-2}
   (C) 0.111×10^{-8} N m^{-2} (D) 0.083×10^{-8} N m^{-2}

5. Electromagnetic wave consists of periodically oscillating electric and magnetic vectors
   (A) in mutually perpendicular planes but vibrating with a phase difference of π
   (B) in mutually perpendicular planes but vibrating with a phase difference of $\frac{\pi}{2}$
   (C) in randomly oriented planes but vibrating in phase
   (D) in mutually perpendicular planes but vibrating in phase.

6. A radio can tune to any station in 7.5 MHz to 12 MHz band. The corresponding wavelength band is
   (A) 40 m to 25 m (B) 30 m to 25 m
   (C) 25 m to 10 m (D) 10 m to 5 m

7. The photon energy in units of eV for electromagnetic waves of wavelength 2 cm is
   (A) 2.5×10^{-19} (B) 5.2×10^{16}
   (C) 3.2×10^{-16} (D) 6.2×10^{-5}

8. A plane electromagnetic wave is incident on a material surface. The wave delivers moment *p* and energy E. Then
   (A) $p \neq 0,\ E \neq 0$ (B) $p = 0,\ E = 0$
   (C) $p = 0,\ E \neq 0$ (D) $p \neq 0,\ E = 0$

9. The charge on a parallel plate capacitor varies as $q = q_0 \cos 2\pi\upsilon t$. The plates are very large and close together (area = A, separation = *d*). The displacement current through the capacitor is

(A) $q_0 2\pi\upsilon \sin \pi\upsilon t$
(B) $-q_0 2\pi\upsilon \sin 2\pi\upsilon t$
(C) $q_0 2\pi \sin \pi\upsilon t$
(D) $q_0 \pi\upsilon \sin 2\pi\upsilon t$

10. If μ_0 be the peremeability and ε0 be the permittivity of a medium, then its refractive index is given by

(A) $\frac{1}{\sqrt{\mu_0\varepsilon_0}}$
(B) $\frac{1}{\mu_0\varepsilon_0}$
(C) $\sqrt{\mu_0\varepsilon_0}$
(D) $\mu_0\varepsilon_0$

11. An electromagnetic wave of frequency υ = 3 MHz passes from vacuum into a dielectric medium with permittivity ε = 4. Then

(A) wavelength and frequency both become half.
(B) wavelength is doubled and frequency remains unchanged.
(C) wavelength and frequency both remain unchanged.
(D) wavelength is halved and frequency remains unchanged.

12. 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, the average force exerted on the surface during a 30 minute time span is

(A) 2.1×10^{-6} N (B) 1.2×10^{-6} N
(C) 1.2×10^{6} N (D) 2.1×10^{6} N

13. Which of the following electromagnetic wave play an important role in maintaining the earth's warmth or average temperature through the greenhouse effect?

(A) Visible rays (B) Infrared waves
(C) Gamma rays (D) Ultraviolet rays

14. Maxwell in his famous equations of electromagnetism introduced the concept of

(A) ac current (B) displacement current
(C) impedance (D) reactance

15. The ultra high frequency band of radiowaves in electromagnetic wave is used as in

(A) television waves
(B) cellular phone communication
(C) commercial FM radio
(D) both A and C

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

(A) is changing with time (B) decreases

(C) does not change (D) decreases to zero

17. 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

18. The electric field part of an electromagnetic wave in a medium is represented by E_x =0,

E_y =2.5 $\frac{N}{C}\cos\left[\left(2\pi\times10^{6}\frac{rad}{m}\right)t-\left(\pi\times10^{-2}\frac{rad}{s}\right)x\right]$, E_z =0 The wave is

(A) moving along *x* direction with frequency 106 Hz and wavelength 100 m

(B) moving along *x* direction with frequency 10^6 Hz and wavelength 200 m

(C) moving along y direction with frequency 10^6 Hz and wavelength 200 m

(D) moving along y direction with frequency $2\pi\times 10^6$ Hz and wavelength 200 m

19. An electromagnetic wave of intensity I falls on a surface kept in vacuum and exerts radiation pressure P on it. Which of the following statement is not true?
(A) Radiation pressure is I/c if the wave is totally absorbed.
(B) Radiation pressure is I/c if the wave is totally reflected.
(C) Radiation pressure is $2I/c$ if the wave is totally reflected.
(D) Radiated. Pressure is in the range $I/c < p < 2\ I/c$ for real surfaces.

20. The rms value of the electric field of the light coming from the sun is 720 NC^{-1}. The average total energy density of the electromagnetic wave is
(A) $3.3 \times 10^{-3} J\ m^{-3}$ (B) $4.58 \times 10^{-6}\ Jm^{-3}$
(C) $6.37 \times 10^{-9}\ Jm^{-3}$ (D) $81.35 \times 10\text{-}^{12}\ Jm^{-3}$

21. The electric field of a plane electromagnetic wave varies with time of amplitude 2 vm^{-1} propagating along z-axis. The average energy density of the magnetic field (in Jm^{-3}) is
(A) 13.29×10^{-12} (B) 8.86×10^{-12}
(C) 17.72×10^{-12} (D) 4.43×10^{-12}

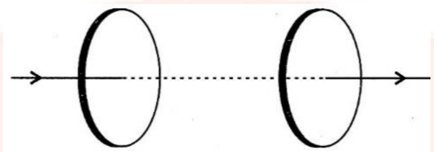
22. A. Wavelength of microwaves is greater than that of ultraviolet rays.
    B. The wavelength of infrared rays is lesser than that of ultraviolet rays.
    C. The wavelength of microwaves is lesser than that of infrared rays.
    D. Gamma ray has shortest wavelength in the electromagnetic spectrum.
    Chose the correct option.
    (A) A and B are true (B) B and C are true
    (C) C and D are true (D) A and D are true

23. X-rays and γ-rays of same energies are distinguished by their
    (A) frequency (B) charges
    (C) ionising power (D) method of production

INTEGERS TYPE QUESTIONS

24. In the above problem, the wavelength of the wave will be –
25. A point source of electromagnetic radiation has an average power output of 800W. The maximum value of electric field at a distance 3.5 m from the source will be –
26. What should be the height of transmitting antenna if the T.V. telecast is to cover a radius of 128 km ?

27. Ac capacitor made of two circular plates each of radius 12 cm and separated by 5 mm. The capacitor is being charged by an external source. The charging current the parallel plate capacitor is



28. A plane electromagnetic wave travels in vacuum along z-direction. If the frequency of the wave is 40 MHz then its wavelength is
29. The electric field associated with an electromagnetic wave in vacuum is given by $\vec{E} = 40\cos\left(kz - 6\times10^{8}t\right)\hat{i},$ where E, z and t are in volt per meter, meter and second respectively. The value of wave vector k is
30. The refractive index and permeability of a medium are 1.5 and $5x10^{-7}$ Hm^{-1} respectively. The relative permittivity of the medium is nearly

SOLUTIONS
MULTIPLE CHOICE QUESTIONS

1. (D)

An electromagnetic wave can be produced by accelerated or oscillating charge. In option (B) and (C), the charge is in accelerated state, hence it will be a source of electromagnetic waves.

2. (A)

Speed of light, $c = \dfrac{1}{\sqrt{\mu_0 \varepsilon_0}}$; Also, $\dfrac{E}{B} = c$

Therefore, $\sqrt{\mu_0 \varepsilon_0}\dfrac{E}{B}$ is dimensionless.

3. (B)

Here, $k = \dfrac{2\pi}{\lambda}$, $\omega = 2\pi\upsilon$

$\therefore \quad \dfrac{k}{\omega} = \dfrac{2\pi/\lambda}{2\pi\upsilon} = \dfrac{1}{\upsilon\lambda} = \dfrac{1}{c} \qquad (\because c = u\lambda)$

where c is the speed of electromagnetic wave in vacuum. It is a constant whose value is 3×10^8 m s^{-1}.

4. (A)

$P = \dfrac{I}{c} = \dfrac{0.5}{3\times10^8} = 0.166\times10^{-8}$ N m^{-2}

5. (D)
Electromagnetic wave consists of periodically oscillating electric and magnetic vectors in mutually perpendicular planes but vibrating in phase.

6. (A)
Here, $\upsilon_1 = 7.5 \text{ MHz}, \upsilon_2 = 12 \text{ MHz}$

$\therefore \quad \lambda_1 = \frac{c}{\upsilon_1} = \frac{3\times10^8}{7.5\times10^6} = 40 \text{ m}$ and $\lambda_2 = \frac{c}{\upsilon_2} = \frac{3\times10^8}{12\times10^6} = 25 \text{ m}$

7. (D)
As $E = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^8}{2\times10^{-2}} = 9.9\times10^{-24} \text{ J} = \frac{9.9\times10^{-24}}{1.6\times10^{-19}} \text{eV} = 6.2\times10^{-5} \text{ eV}$

8. (A)
When plane electromagnetic wave is incident on a material surface, the wave delivers some momentum and energy to the surface and hence $p \neq 0$ and $\mathrm{E} \neq 0$.

9. (B)
Displacement current, I_D = conduction current, I_C

$\therefore \quad \frac{dq}{dt} = \frac{d}{dt}\left[q_0 \cos 2\pi\upsilon t\right] = -q_0 2\pi\upsilon \sin 2\pi\upsilon t$

10. (C)

Refractive index of medium is $= \frac{c}{v}$

where $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$ and $v = \frac{1}{\sqrt{\mu_0 \varepsilon_0 \mu_r \varepsilon_r}}$

$\therefore \quad \mu = \frac{1/\sqrt{\mu_0 \varepsilon_0}}{1/\sqrt{\mu_0 \varepsilon_0 \mu_r \varepsilon_r}} = \sqrt{\mu_r \varepsilon_r}$

Given $\mu_r = \mu_0$ and $\varepsilon_r = \varepsilon_0$ then $\mu = \sqrt{\mu_r \varepsilon_0}$

11. (D)

The frequency of electromagnetic wave remains unchanged but the wavelength of electromagnetic wave changes when it passes from one medium to another.

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

$\therefore \quad c \propto \frac{1}{\sqrt{\varepsilon_0}}$ and $v \propto \frac{1}{\sqrt{\varepsilon}}$

$\therefore \quad \frac{c}{v} = \sqrt{\frac{\varepsilon}{\varepsilon_0}} = \sqrt{\frac{4}{1}} = 2; \frac{c}{v} = \frac{\upsilon\lambda}{\upsilon\lambda'} = \frac{\lambda}{\lambda'} = 2$ or $\lambda' = \frac{\lambda}{2}$

12. (B)

The total energy falling on the surface is U = 18 × 20 × (30 × 60) = 6.48 × 10^5 J

Therefore, the total momentum delivered (for complete absorption is)

$$p = \frac{U}{c} = \frac{6.48 \times 10^5}{3 \times 10^8} = 2.16 \times 10^{-3} \text{ kg m s}^{-1}.$$

The average force exerted on the surface is

$$F = \frac{p}{t} = \frac{2.16\times10^{-3}}{0.18\times10^{4}} = 1.2\times10^{-6} \text{ N}$$

13. (B)

Infrared radiation plays an important role in maintaining the earth's warmth through greenhouse effect. Incoming visible light when passes relatively easily through the atmosphere is absorbed by the earth's surface and radiated as infrared (longer wavelength) radiation. This radiation is trapped by greenhouse gases such as carbon dioxide and water vapour. In this way an average temperature is maintained.

14. (B)

15. (B)

16. (A)

Displacement current arises when electric field in a region is changing with time. It will be so if the charge on a capacitor is changing with time.

17. (D)

Microwaves are used to cook food. Microwave oven is a domestic application of these waves.

18. (B)

$$E_y = 2.5\frac{N}{C}\times\cos\left[\left(2\pi\times10^6\frac{rad}{m}\right)t - \left(\pi\times10^{-2}\frac{rad}{s}\right)x\right]$$

$$E_z = 0,\ E_x = 0$$

The wave is moving in the positive direction of x.

This is in the form $E_y = E_0\cos(\omega t - kx)$

$$\omega = 2\pi\times10^6$$

$$2\pi v = 2\pi\times10^6 \Rightarrow \upsilon = 10^6\ \text{Hz}$$

$\frac{2\pi}{\lambda} = k \Rightarrow \frac{2\pi}{\lambda} = \pi\times10^{-2}$ or $\lambda = 200$ m

19. (B)

Momentum per unit time per unit area $= \frac{\text{intensity}}{\text{speed of wave}} = \frac{I}{c}$

Change in momentum per unit time per unit area = $\Delta I/c$ = radiation pressure (P), i.e. P = $\Delta I/c$.

Momentum of incident wave per unit time per unit area = I/c

When wave is fully absorbed by the surface, the momentum of the reflected wave per unit time per unit area = 0

Radiation pressure (P) = change in momentum per unit time per unit area $= \frac{\Delta I}{c} = \frac{I}{c} - 0 = \frac{I}{c}$

When wave is totally reflected, then momentum of the reflected wave per unit time per unit area = –I/c

Radiation pressure (P) $= \frac{I}{c} - \left(-\frac{K}{c}\right) = \frac{2I}{c}$

Here, P lies between $\frac{I}{c}$ and $\frac{2I}{c}$.

20. (B)

Total average energy density of electromagnetic wave is

$$U_{av} = \frac{1}{2}\varepsilon_0 E_{rms}^2 + \frac{1}{2\mu_0} B_{rms}^2 = \frac{1}{2}\varepsilon_0 E_{rms}^2 + \frac{1}{2\mu_0}\left(\frac{E_{rms}^2}{c^2}\right) \qquad \left(\because B_{rms} = \frac{E_{rms}}{c}\right)$$

$$= \frac{1}{2}\varepsilon_0 E_{rms}^2 + \frac{1}{2\mu_0} E_{rms}^2 \varepsilon_0 \mu_0 \qquad \left(\because c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}\right)$$

$$= \frac{1}{2}\varepsilon_0 E_{rms}^2 + \frac{1}{2}\varepsilon_0 E_{rms}^2 = \varepsilon_0 E_{rms}^2$$

$$= 8.85 \times 10^{-12} \times (720)^2 = 4.58 \times 10^{-6}\ \mathrm{J\,m^{-3}}$$

21. (B)

Amplitude of electric field and magnetic field are related by the relation.

$$\frac{E_0}{B_0} = c$$

Average energy density of the magnetic field is $u_B = \frac{1}{4}\frac{B_0^2}{\mu_0} = \frac{1}{4}\frac{E_0^2}{\mu_0 c^2}$

$$\left(\because B_0 = \frac{E_0}{c}\right)$$

$$= \frac{1}{4}\varepsilon_0 E_0^2 = \frac{1}{4} \times 8.854 \times 10^{-12} \times (2)^2 = 8.854 \times 10^{-12}\ \mathrm{J\ m^{-3}} = 8.86 \times 10^{-12}\ \mathrm{J\ m^{-3}}$$

22. (D)

$$\lambda_{micro} > \lambda_{infrared} > \lambda_{ultraviolet} > \lambda_{gamma}$$

23. (D)

INTEGERS TYPE QUESTIONS

24. 1.5

Wavelength of electromagnetic wave

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

25. 62.6

Intensity of electromagnetic wave given is by $I = \frac{P_{av}}{4\pi r^2} = \frac{E_m^2}{2\mu_o c}$

$E_m = \sqrt{\frac{\mu_o c P_{av}}{2\pi r^2}} = \sqrt{\frac{(4\pi\times10^{-7})\times(3\times10^8)\times800}{2\pi\times(3.5)^2}} = 62.6\ V/m$

26. 1280 m

Height of transmitting antenna $h = \frac{d^2}{2R_e} = \frac{(128\times10^3)^2}{2\times6\cdot4\times10^6} = 1280\,m$

27. (80 pF)

Here, R = 12 cm = 0.12 m

d = 5 mm = 5 × 10^{-3} m, ε0 = 8.85 × 10^{-12} C^2 N^{-1} m^{-2}

Also, $A = \pi R^2 = 3.14\times(0.12)^2\,m^2 = 4.5\times10^{-2}\,m^2$

Capacitance, $C = \frac{\varepsilon_0 A}{d} = \frac{8.85\times10^{-12}\times4.5\times10^{-2}}{5\times10^{-3}} = 79.65\times10^{-12} = 80\ pF$

28. 7.5 m

Wavelength, $\lambda = \frac{c}{\upsilon} = \frac{3\times10^8\,m\,s^{-1}}{40\times10^6\,s^{-1}} = 7.5\ m$

29. 2 m^{-1}

Compare the given equation with $E = E_0\cos(kz - \omega t)$

We get, $\omega = 6\times10^{8}\ \text{s}^{-1}$

$\therefore$ Wave vector, $k = \dfrac{\omega}{c} = \dfrac{6\times10^{8}\,\text{s}^{-1}}{3\times10^{8}\,\text{m}\,\text{s}^{-1}} = 2\,\text{m}^{-1}$

30. (5.65)

Refractive index, $n = \dfrac{c}{v}$

or $v = \dfrac{c}{n} = \dfrac{3\times10^{8}}{1.5} = 2\times10^{8}\ \text{m s}^{-1}$

Here, $\mu = 5\times10^{7}$ H m^{-1}

$\therefore$ $v = \dfrac{1}{\sqrt{\mu\varepsilon}} = \dfrac{1}{\sqrt{\mu\varepsilon_0\varepsilon_r}}$

$$\varepsilon_r = \frac{1}{v^2\mu\varepsilon_0} = \frac{1}{\left(2\times10^{8}\right)^2\times\left(5\times10^{-7}\right)\times\left(8.85\times10^{-12}\right)}$$

$= 5.65$