ELECTROMAGNETIC WAVES

CHAPTER 08

❖ **Light may be described as a wave.**

(i) Wave equation for light travelling in $+X$ direction in vacuum is

$$E = E_0 \sin \omega(t - x/c) \quad \ldots(i)$$

(ii) Similarly, there is sinusoidally varying magnetic field associated with electric field with equation.

$$B = B_0 \sin \omega(t - x/c) \quad \ldots(ii)$$

Which is perpendicular to direction of E and direction of propagation.

Combination of mutually perpendicular electric and magnetic fields is referred to an **electromagnetic wave** in vacuum.

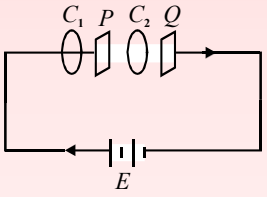
Maxwell's displacement current

➢ According to ampere's circuital law

$$\oint \vec{B} . \vec{dl} = \mu_0 \, i_{\text{enclosed}} \quad \ldots(i)$$

Consider || plates capacitor with plates P and Q. During charging current I flows through the connecting wires which changes with time.

Consider two loops C_1 and C_2. C_1 enclosed the wire and C_2 encloses the space. C_1 and C_2 are parallel to the plates.



C_1 enclose I

$$\therefore \quad \oint_{C_1} \vec{B} . \vec{dl} = \mu_0 I \quad \ldots(i)$$

C_2 enclose no current

$$\therefore \quad \oint_{C_2} \vec{B} . \vec{dl} = 0 \quad \ldots(ii)$$

If C_1 and C_2 are infinitesimally close to each other then it is expected that (i) = (ii). Hence to correct it Maxwell gave idea of displacement current.

"Time varying electric field also produces a magnetic field. Hence a changing electric field gives rise to a current which flow through a region, as long as the electric field is changing there."

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Example-1: **Find the rate of change of voltage for displacement current of 2A in the space between the plates of a 1μF capacitor.**

Solution: $I_d = C.\frac{dV}{dt}$ $\quad 2 = 1\times10^{-6}\times\frac{dV}{dt}$ or $\frac{dV}{dt} = 2\times10^{6}$ volt/sec.

❖ Maxwell's equations

(1) Gauss's law for electrostatic $\oint \vec{E}.\vec{ds} = \frac{q_{in}}{\epsilon_0}$.

(2) Gauss's law for magnetism $\oint \vec{B}.\vec{ds} = 0$

(3) Faraday's law in electromagnetic induction $\oint \vec{E}.\vec{dl} = -\frac{d\phi_B}{dt}$

(4) Ampere's circuital law $\oint \vec{B}.\vec{dl} = \mu_0\left[I + \epsilon_0\frac{d\phi_E}{dt}\right]$

(Where current and changing electric field, both are present)

These equations are collectively known as Maxwell's equation.

In vacuum there are no charge and hence no conduction current $\therefore$ $q_{in} = 0$, $I = 0$ hence

(i) $\oint \vec{E}.\vec{ds} = 0$

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

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

(iv) $\oint \vec{B}.\vec{dl} = \mu_0\epsilon_0\frac{d\phi_E}{dt}$

Example-2: **How will Gauss's law in magnetostatics be modified if monopoles do exist?**

Solution: $\oint \vec{B}.\vec{ds} = m \times$ constant, where 'm' is the pole strength.

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❖ Properties of electromagnetic waves

(i) Electro-magnetic waves are produced by accelerating (so that E and B both change with time) or oscillating charge.

(ii) There is no requirement of medium to propagate em wave.

(iii) These are transverse in nature. (like light waves)

(iv) Velocity of e.m waves in dielectrics are less than c.

(v) The energy in e.m waves are divided equally between electric and magnetic field *i.e.* $\frac{B_0^2}{2\mu_0} = \frac{1}{2} \in_0 E^2$.

(vi) Electric vector gives optical effect and is called light vector.

(vii) e.m. waves being uncharged are not deflected by electric and magnetic fields.

(viii) $c = E_o / B_o$

(ix) $c = \sqrt{\frac{1}{\mu_0 \in_o}}$

(x) Energy density $U_{av.}(\text{electric}) = \frac{1}{4} \in_0 E_0^2$; Where $E = E_0 \sin\omega(t - x/c)$

(xi) Energy density $U_{av.}(\text{magnetic}) = \frac{1}{4} \frac{B_0{}^2}{\mu_0}$

$\boxed{U_{av}^{(E)} = U_{av}^{(B)}}$ where $B = B_0 \sin\omega(t - x/c)$ Total Energy Density $= \frac{1}{2} \in_0 E_0^2$

(xii) Energy crossing/unit area/unit time perpendicular to the direction of motion is called intensity of wave. $I = \left(\frac{1}{2} \in_0 E^2\right).c$.

Example-3: **If 40% of radio waves of intensity $3\,\text{W/m}^2$ is absorbed at a surface, find the pressure exerted on the surface in N/m².**

Solution: When 40% of intensity is absorbed, the reflected intensity is 60% therefore, the pressure exerted on the surface $= \frac{I}{c} + \frac{60}{100}\frac{I}{c} = 1.6\frac{I}{c}$ where, $c = 3\times10^8$ m/sec.

$$= 1.6 \times \frac{3}{3\times10^8} = 1.6\times10^{-8}\ \text{N/m}^2.$$

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Example-4: **A radio wave of intensity 60 W/m^2 is completely absorbed by a surface. What is the radiation pressure exerted by the wave on the surface?**

Solution: When a radio wave is completely absorbed by a surface then the pressure exerted on the surface

$$= \frac{I}{c} = \frac{60 \text{ W/m}^2}{3\times10^8 \text{ m/sec}} = 20\times10^{-8} = 2\times10^{-7} \text{ N/m}^2 .$$

Example-5: **If amplitude of magnetic field of an electromagnetic wave is 2.0×10^{-5}T, find the amplitude of electric field?**

Solution: Amplitude of electric field, $E_0 =$ velocity of light $\times$ B_0.

$$E_0 = (3\times10^8 \text{ m/s})\times(2\times10^{-5} \text{ T}) = 6\times10^3 \text{ V/m}$$

Electromagnetic Spectrum

➢Electromagnetic waves extend over a wide range of wavelengths (from less than 10^{-15} m to hundreds of km) or frequencies. Waves of various wavelength ranges have got different names mainly according to their origin. These are given below (in increasing order of wavelength)

(a) Gamma rays – 10^{-3} Å to 1Å

(b) X-rays – 0.1Å to 100Å

(c) Ultraviolet rays – 100Å to 4000Å

(d) Visible light – 4000Å to 7000Å

(e) Infrared rays – 7000Å to 10,000Å

(f) Heat radiation – 10^4 Å to 0.1 cm

(g) Microwaves – 0.1 cm to 10 m

(h Radio waves – 1m to 10^3 m

(i) Long waves – 1 km to 1000 km

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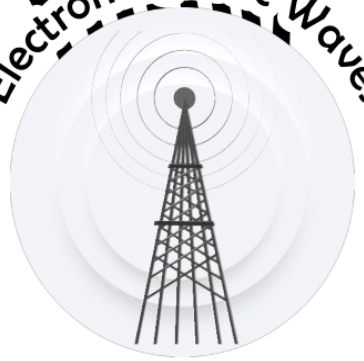
Electromagnetic Waves



History

In 1886 Heinrich Hertz became the first person to transmit and receive controlled radio signal.

Conduction current

The current due to flow of charge is often called conduction current,

$$I_c = \frac{dq}{dt}$$

Displacement current

If there exists an electric current as well as a changing electric field, if results magnetic field and causes displacement current,

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

Electromagnetic spectrum

- **Radio waves :** $\lambda > 10^8$ nm
  Use : radio, TV signal
- **Micro waves :** $10^8 > \lambda > 10^5$ nm
  Use : micro wave oven, radar
- **Infrared :** $10^5 > \lambda > 700$ nm
  Use : night vision
- **Visible light :** $700 > \lambda > 400$ nm
  Use : to observe world
- **UV rays :** $400 > \lambda > 10$ nm
  Use : destroying bacteria
- **X-rays :** $10 > \lambda > 0.01$ nm
  Use : detect bone break
- **γ rays :** $0.01 \text{ nm} > \lambda$
  Use : to treat cancer

Maxwell's equations

Gauss's law (electricity)

$$\oint \vec{E}.\vec{ds} = \frac{q_{in}}{\varepsilon_0}$$

Gauss's law (magnetism)

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

Faraday's law

$$\oint \vec{E}.\vec{dl} = \frac{-d\phi_B}{dt}$$

Ampere's law

$$\oint \vec{B}.\vec{dl} = \mu_0 I + \mu_0\varepsilon_0 \frac{-d\phi_E}{dt}$$

Characteristics of Electromagnetic waves

- Do not need any material medium for propagation
- Travel with speed of light $(c) = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$
- Produced be accelerated charged particle
- Transverse in nature
- Oscillating electric & magnetic fields are in phase and their ratio is constant
  $(c) = \frac{aE_0}{B_0}$

Combination of mutually perpendicular electric and magnetic fields is referred to as an electromagnetic wave

Energy density

- $U = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\frac{B^2}{\mu_0}$ = Total energy per unit volume
- U_{av} over a long time

$$U_{av} = \frac{1}{4}\varepsilon_0 E_0^2 + \frac{1}{4}\frac{B_0}{\mu_0}$$

$$= \frac{1}{2}\varepsilon_0 E_0^2 \quad [\text{as } c = \frac{E_0}{B_0} \text{ and } \mu_0\varepsilon_0 = \frac{1}{c^2}]$$

$$= \frac{1}{2}\frac{B_0^2}{\mu_0}$$

Trace the Mind Map

First Level · Second Level · Third Level

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PRACTICE QUESTIONS

1. According to Maxwell's hypothesis, a changing electric field gives rise to
   a) An emf b) Electric current c) Magnetic field d) Pressure radiant

2. Electric fields induced by changing magnetic fields are
   a) Conservation b) Non-conservation
   c) May be conservative or non-conservation depending on the conditions d) Nothing can be said

3. 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 is (in Jm^{-3})
   a) 13.29×10^{-12} b) 8.86×10^{-12} c) 17.72×10^{-12} d) 4.43×10^{-12}

4. The sun delivers 10^4 Wm^{-2} of electromagnetic flux to the earth's surface. The total power that in incident on a roof of dimensions 10m square will be
   a) 10^4W b) 10^5 W c) 10^6 W d) 10^7 W

5. Infrared radiation is detected by
   a) Spectrometer b) Pyrometer c) Nanometer d) Photometer

6. Ground waves have wavelength
   a) Less than 200 m b) Equal to 200 m c) More than 200 m d) All of these

7. A plane Electromagnetic Waves travelling along the X-direction has a wavelength of 3 mm. The variation in the electric field occurs in the Y-direction with an amplitude 66 Vm^{-1}. The equations for the electric and magnetic fields as a function of x and t are respectively

a) $E_y = 33\cos\pi \times 10^{11}\left(t - \frac{x}{c}\right)$,
$B_z = 1.1 \times 10^{-7}\cos\pi \times 10^{11}\left(t - \frac{x}{c}\right)$

b) $E_y = 11\cos 2\pi \times 10^{11}\left(t - \frac{x}{c}\right)$,
$B_y = 11 \times 10^{-7}\cos 2\pi \times 10^{11}\left(t - \frac{x}{c}\right)$

c) $E_x = 33\cos\pi \times 10^{11}\left(t - \frac{x}{c}\right)$,
$B_x = 11 \times 10^{-7}\cos\pi \times 10^{11}\left(t - \frac{x}{c}\right)$

d) $E_y = 66\cos 2\pi \times 10^{11}\left(t - \frac{x}{c}\right)$,
$B_z = 2.2 \times 10^{-7}\cos 2\pi \times 10^{11}\left(t - \frac{x}{c}\right)$

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8. The frequency 1057 MHz of radiation arising from two close energy levels in hydrogen belongs
   a) Radio waves b) Infrared waves c) Micro waves d) $\gamma -$ rays

9. Maxwell in his famous equation of electromagnetism introduced the concept
   a) AC current b) DC current c) Displacement current d) Impedance

10. In a plane electromagnetic wave electric field varies with time having an amplitude 1 $\mathrm{Vm^{-1}}$. The frequency of wave is 0.5×10^{15} Hz. The wave is propagation along X-axis. What is the average energy density of magnetic field?
   a)$1.1 \times 10^{-12}\mathrm{J\ m^{-3}}$ b) $2.2 \times 10^{-12}\mathrm{J\ m^{-3}}$ c) $3.3 \times 10^{-12}\mathrm{J\ m^{-3}}$ d) $4.4 \times 10^{-12}\mathrm{J\ m^{-3}}$

11. An Electromagnetic Wave of frequency v = 3.0 MHz passes from vacuum into a dielectric medium with permittivity $\varepsilon = 4.0$. Them
   a) Wavelength is doubled and the frequency remains unchanged
   b) Wavelength is doubled and frequency becomes half
   c) Wavelength is halved and frequency remains unchanged
   d) Wavelength and frequency both become unchanged

12. The amplitude of electric field in a parallel beam of light of intensity 4 $\mathrm{Wm^{-2}}$ is
   a) $40.5\ \mathrm{NC^{-1}}$ b) $45.5\ \mathrm{NC^{-1}}$ c) $50.5\ \mathrm{NC^{-1}}$ d) $55.5\ \mathrm{NC^{-1}}$

13. Assume that a lamp radiates power P uniformly in all directions. What is the magnitude of electric field strength at a distance r from the lamp?
   $a)\ \dfrac{P}{\pi c \varepsilon_0 r^2}$ b) $\dfrac{P}{2\pi c \varepsilon r^2}$ c) $\sqrt{\dfrac{P}{2\pi\varepsilon_0 r^2 c}}$ d) $\sqrt{\dfrac{P}{\pi\varepsilon_0 c r^2}}$

14. The wavelength of infrared rays is of the order of
   $a)\ 5 \times 10^{-7}\mathrm{m}$ b) $10^{-3}\mathrm{m}$ c) Diverge more d) None of these

15. Molybdenum is used as a target element for the production of X-rays because it is
   a) Light and can easily defect electrons b) Light and can absorb electrons
   c) A heavy element with a high melting d) An element having high thermal conductivity

16. A charged particle with charge q enters a region of constant, uniform and mutually orthogonal fields **E** and **B** with a velocity **v** perpendicular to both **E** and **B**, and comes out without any change in magnitude or direction of **v.** Then
   a) $\mathbf{v} = \mathbf{E} \times \dfrac{\mathbf{B}}{\mathrm{B}^2}$
   b) $\mathbf{v} = \mathbf{B} \times \dfrac{\mathbf{E}}{\mathrm{B}^2}$
   c) $\mathbf{v} = \mathbf{E} \times \dfrac{\mathbf{B}}{\mathrm{E}^2}$
   d) $\mathbf{v} = \mathbf{B} \times \dfrac{\mathbf{E}}{\mathrm{E}^2}$

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17. If v_s, v_x and v_m are the speeds of gamma rays, X-rays and microwaves respectively in vacuum, then

a) $v_s > v_x > v_m$ b) $v_s < v_x < v_m$ c) $v_s < v_x < v_m$ d) $v_s = v_x = v_m$

18. The small ozone layer on top of the atmosphere is crucial for human survival because it

a) Has ions b) Reflects radio signals c) Absorbs UV rays d) Reflects IR rays

19. Television signals reach us only through the ground waves. The range R related with the transmitter height h is in proportion to

a) h b) $h^{1/2}$ c) $h^{-1/2}$ d) h^{-1}

20. In a plane electromagnetic wave propagating in space has an electric field of amplitude $9 \times 10^3\ \mathrm{Vm^{-1}}$, then the amplitude of the magnetic field is

a) 2.7×10^{12} T b) 9.0×10^{-3} T c) 3.0×10^{-4} T d) 3.0×10^{-5} T

21. A capacitor having a capacity of 2 pF. Electric field across the capacitor is changing with a value of $10^{12}\ \mathrm{Vs^{-1}}$. The displacement current is

a) 2 A b) 4 A c) 6 A d) 10 A

22. If 150 J of energy is incident on area 2 m^2. If $Q_r = 15$ J, coefficient of absorption is 0.6, then amount of energy transmitted is

a) 50 J b) 45 J c) 40 J d) 30 J

23. Radiations of intensity 0.5 Wm^{-2} are striking a metal plate. The pressure on the plate is

a) $0.166 \times 10^{-8}\ \mathrm{Nm^{-2}}$
b) $0.332 \times 10^{-8}\ \mathrm{Nm^{-2}}$
c) $0.111 \times 10^{-8}\ \mathrm{Nm^{-2}}$
d) $0.083 \times 10^{-8}\ \mathrm{Nm^{-2}}$

24. A charged particles oscillates about its mean equilibrium position with a frequency of 10^9 Hz. Frequency of the Electromagnetic Waves produced by the oscillator is

a) 10 Hz b) 10^5 Hz c) 10^9 Hz d) 10^{10} Hz

25. The unit of expression $\mu_0\varepsilon_0$ are

a) $\mathrm{ms^{-1}}$ b) $\mathrm{m^2s^{-2}}$ c) $\mathrm{s^2m^{-2}}$ d) $\mathrm{sm^{-1}}$

26. A layer of ionosphere does not reflect waves with frequencies greater than 10 MHz; then maxim electron density in this layer is

a) $1.23 \times 10^{11}\ \mathrm{m^{-3}}$ b) $1.23 \times 10^{10}\ \mathrm{m^{-3}}$ c) $12.3 \times 10^{10}\ \mathrm{m^{-3}}$ d) $1.23 \times 10^{12}\ \mathrm{m^{-3}}$

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27. 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 Vm^{-1} is

a) 500 b) 100 c) $\frac{500}{3}$ d) $\frac{250}{3}$

28. A. The wavelength of microwaves is greater than that of UV-rays.
B. The wavelength of IR rays is lesser than that of UV-rays.
C. The wavelength of microwaves is lesser than that of IR-rays.
D. Gamma rays have shortest wavelength in the Electromagnetic Spectrum.
Of the above statements

a) A and B are true b) B and C are true
c) C and D are true d) A and D are true

29. If μ_0 is permeability of free space and ε_0 is permittivity of free space, the speed of light in vacuum is given by

$a)\ \sqrt{\mu_0\varepsilon_0}$ b) $\sqrt{\frac{\mu_0}{\varepsilon_0}}$ c) $\sqrt{\frac{1}{\mu_0\varepsilon_0}}$ d) $\sqrt{\frac{\varepsilon_0}{\mu_0}}$

30. A plane electromagnetic wave of intensity 10 Wm^{-2} strikes a small mirror of area 20 cm^2, held perpendicular to the approaching wave. The radiation force on the mirror will be

a) 6.6×10^{-11} N b) 1.33×10^{-11} N c) 1.33×10^{-10} N d) 6.6×10^{-10} N

31. A plane Electromagnetic Waves travels in free space along x-axis. At a particular point in space, the electric field along y-axis is 9.3 Vm^{-1}. The magnetic induction is

$a)\ 3.1 \times 10^{-8}\ T$ b) $3 \times 10^{-5}\ T$ c) $3 \times 10^{-6}\ T$ d) $9.3 \times 10^{-6}\ T$

32. Clouds are contained in a layer from the earth's surface, which is called

a) Troposphere b) Stratosphere c) Mesosphere d) Ionosphere

33. The correct sequence of the increasing wavelength of the given radiation sources is

a) Radioactive sources, X-ray tube, crystal oscillator, sodium vapour lamp
b) Radioactive source, X-ray tube, sodium vapour lamp, crystal oscillator
c) X-ray tube, radioactive source, crystal oscillator, sodium vapour lamp
d) X-ray tube, crystal oscillator, radioactive source, sodium vapour lamp

34. 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 equation is true?

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

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35. If alpha, beta and gamma rays carry same momentum, which has the longest wavelength?
a) Alpha rays b) Beta rays
b) Gamma rays d) None, all have same wavelength

36. The curve drawn between velocity and frequency of a photon in vacuum will be
a) Straight line parallel to frequency axis b) Straight line parallel to velocity axis
c) Straight line passing through origin and making an angle of 45° with frequency axis d) Hyperbola

37. An Electromagnetic Wave has
a) Electric vector only
b) Magnetic vector only
c) Electric and Magnetic vector Perpendicular to each other
d) Neither the Electric vector nor the Magnetic vector

38. An electromagnetic radiation has an energy of 13.2 keV. Then the radiation belongs to the region of
a) Visible light b) Ultraviolet c) Infrared d) X-ray

39. The electric field of plane electromagnetic wave in vacuum is represented by $\vec{\mathbf{E}}_x = 0; \vec{\mathbf{E}}_y = 0.5\cos[2\pi \times 10^8(t - x/c)]: \vec{\mathbf{E}}_z = 0$
What is the direction of propagation of electromagnetic waves?
a) Along $x - z$ direction b) Along y-direction
c) Along x-direction d) A long $y - z$ direction

40. An expression for the magnetic field strength B at the point between the capacitor plates indicates in figure express B in terms of the rate of change of the electric field strength $ie, dE/dt$ between the plates
a) $\frac{\mu_0 i}{2\pi r}$ b) $\frac{\varepsilon_0 \mu_0 r}{2} dE/dt$ c) Zero d) $\frac{\mu_0 i}{2r}$

41. The temperature variation in the region of stratosphere lies from
a) 290 K to 220 K b) 220 K to 280 K c) 220 K to 380 K d) 180 K to 700 K

42. Which is having minimum wavelength?
a) X-rays b) Ultraviolet rays c) γ-rays d) Cosmic rays

43. The voltage applied across an X-ray tube is nearly equal to
a) 10 V b) 100 V c) 1000 V d) 10, 000 V

44. Given the wavefunction (in SI units) for a wave to be $\psi_{(x,t)} = 10^3 \sin\pi(3 \times 10^6\, x - 9 \times 10^{14}\, t)$ The speed of the wave is
a) 9×10^{14} ms^{-1} b) 3×10^8 ms^{-1} c) 3×10^6 ms^{-1} d) 3×10^7 ms^{-1}

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----------ANSWER KEY----------

			1)	c			
2)	b	3)	b	4)	c	5)	b
6)	c	7)	d	8)	a	9)	c
10)	b	11)	c	12)	d	13)	c
14)	c	15)	c	16)	a	17)	d
18)	c	19)	b	20)	d	21)	a
22)	b	23)	a	24)	c	25)	c
26)	d	27)	b	28)	d	29)	c
30)	c	31)	a	32)	a	33)	b
34)	a	35)	d	36)	b	37)	c
38)	d	39)	c	40)	b	41)	b
42)	c	43)	d	44)	b		

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HINTS AND SOLUTIONS

1. (c)
According to Maxwell, a changing electric field is a source of magnetic field

2. (b)
The electric field induced by changing magnetic field depends upon the rate of change of magnetic flux, hence it is non-conservative

3. (b)
$U = \frac{1}{2} \times \frac{1}{2}\varepsilon_0 E^2 = \frac{1}{2} \times \frac{1}{2} \times 8.85 \times 10^{-12} \times (2)^2$
$= 8.85 \times 10^{-12} \text{Jm}^{-3}$

4. (c)
Total power=solar constant × area
$= 10^4 \times (10 \times 10) = 10^6$ W

5. (b)
Infrared radiations are detected by pyrometer

6. (a)

7. (d)
The equation of electric field occurring in Y-direction
$$E_y = 66 \cos 2\pi \times 10^{11}\left(t - \frac{x}{c}\right)$$
Therefore, for the magnetic field in Z-direction
$$B_z = \frac{E_y}{c}$$
$$= \left(\frac{66}{3 \times 10^8}\right) \cos 2\pi \times 10^{11}\left(t - \frac{x}{c}\right)$$
$$= 22 \times 10^{-8} \cos 2\pi \times 10^{11}\left(t - \frac{x}{c}\right)$$
$$= 22 \times 10^{-7} \cos 2\pi \times 10^{11}\left(t - \frac{x}{c}\right)$$

8. (a)
Radio waves have a frequency of 1057 M H z that result from two near hydrogen energy levels.

9. (c)
Maxwell explained the concept of displacement current using the case of a capacitor. That is when a capacitor starts charging, there is no charge conduction between the fields. However, due to charge accumulation in the plates with time, electric field changes causing the displacement current.

10. (b)
In an electromagnetic wave, the average energy density of magnetic field μ_B = average energy density of electric filed $v_E = \frac{1}{4}\varepsilon_0 E_0^2$
$$= \frac{1}{4} \times (8.85 \times 10^{-12}) \times 1^2$$
$$= 2.21 \times 10^{-12} \text{ Jm}^{-3}$$

11. (c)
In vacuum, ε_0=1
In medium, $\varepsilon = 4$
So, refractive index
$$\mu = \sqrt{\varepsilon/\varepsilon_0} = \sqrt{4/1} = 2$$
wavelength $\lambda' = \frac{\lambda}{\mu} = \frac{\lambda}{2}$
and wave velocity $v = \frac{c}{\mu} = \frac{c}{2}$
Hence, it is clear that wavelength and velocity will become half but frequency remains uncharged when the wave is passing through any medium.

12. (d)
$I = \frac{1}{2}\varepsilon_0 E_0^2 c$
or $E_2 = \sqrt{\frac{2I}{\varepsilon_0 c}}$
$$= \sqrt{\frac{2 \times 4}{(8.85 \times 10^{-12}) \times (3 \times 10^8)}} = 55.5 \text{ NC}^{-1}$$

13. (c)
Intensity $I = \frac{\text{pressure}}{\text{area}} = \frac{p}{4\pi r^2}$
=average energy density × velocity
$$= \frac{1}{2}\varepsilon_0 E_0^2 c \therefore E_0 = \sqrt{\frac{2P}{4\pi\varepsilon_0 r^2 c}} = \sqrt{\frac{P}{2\pi\varepsilon_0 r^2 c}}$$

(b)
The electric field induced by changing magnetic field depends upon the rate of change of magnetic flux, hence it is non-conservative

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14. (c)
The wavelengths of infrared rays lie between 7800 Å to 0.004 cm

15. (c)
Molybdenum is used as a target element for production of X - rays because in X-ray tube, target must be heavy element with high melting point.

16. (a)
As **v** of charged particle is remaining constant, it means force acting on charged particle is zero.
So, $q(\mathbf{v} \times \mathbf{B}) = q\mathbf{E}$

$$\Rightarrow \quad \mathbf{v} \times \mathbf{B} = \mathbf{E}$$

$$\Rightarrow \quad \mathbf{v} = \frac{\boldsymbol{E} \times \boldsymbol{B}}{B^2}$$

17. (d)
The gamma rays, X– rays and the microwaves are the Electromagnetic waves and the speed of all the electromagnetic waves remains the same in vacuum irrespective of other parameters. All will travel at the speed of light.
Vg=Vx=Vm

The speed of Electromagnetic waves is always the same in vacuum

18. (c)
An ozone layer, present in the stratosphere, reflects the ultraviolet rays emitted by the sun and thus it prevents us from skin diseases and mutation.

19. (b)
Range, $R = \sqrt{2hr}$ where r is the radius of earth so $R \propto h^{1/2}$

20. (d)

$$B_0 = \frac{E_0}{c} = \frac{9 \times 10^3}{3 \times 10^8} = 3 \times 10^{-5}\ \text{T}$$

21. (a)

$$i = \frac{dQ}{dt} = \frac{d}{dt}(CV)$$

$$= C\frac{dV}{dt} = 2 \times 10^{-12} \times 10^{12} = 2\ \text{A}$$

22. b)
When thermal radiations (Q) fall on a body, they are partly reflected, partly absorbed and partly transmitted.

$$Q = Q_a + Q_r + Q_t$$

And $\frac{Q_a}{Q} + \frac{Q_r}{Q} + \frac{Q_t}{Q} =$

$$a + r + t = 1$$

$$\Rightarrow \quad \frac{15}{150} + 0.6 + x = 1$$

or $\quad 0.1 + 0.6 + x = 1$

or $\quad x = 0.3$

Transmitting power, $t = \frac{Q_t}{Q}$

Or $\quad 0.3 = \frac{Q_t}{150}$

$$\Rightarrow \quad Q_t = 45\ \text{J}$$

23. (a)
Intensity or power per unit area of the radiations,

$$P = pv$$

$$\Rightarrow \quad p = \frac{P}{v}$$

$$= \frac{0.5}{3 \times 10^8} = 0.166 \times 10^{-8}\ \text{Nm}^{-2}$$

24. (c)
The frequency of Electromagnetic Waves produced by the oscillator is equal to the frequency of the oscillating particle $ie, 10^9$ Hz.

25. (c)

Velocity of light, $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$

or $\mu_0 \varepsilon_0 = \frac{1}{c^2} = \frac{1}{(\text{ms}^{-1})^2} = \text{s}^2\text{m}^{-2}$

26. (d)
If maximum electron density of the ionosphere is N_{max} per $m^3$3,
then $fc=9\,(N_{max})^{1/2}$

Above fc a wave will penetrate the ionosphere and is not reflected by it.
or $N_{max} = (fc)^2/81$
or $N_{max} = (10\times10^6)^2/81$
or $N_{max} = 1.23\times10^{12}\text{m}^{-3}$

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27. (b)

28. (d)

The wavelength order of the given types of waves are given below

Waves	**Wavelength Range (in meter)**
Gamma rays	$10^{-14} - 10^{-10}$
IR-rays	$7 \times 10^{-7} = 10^{-3}$
UV-rays	$10^{-9} - 4 \times 10^{-7}$
Microwave	$10^{-4} - 10^{0}$

Hence, statements (A) and (D) are correct.

29. (c)

The speed of light in vacuum is given by $\sqrt{\frac{1}{\mu_0 \varepsilon_0}}$, where μ_0 is permeability and ε_0 is permittivity of free space.

30. (c)

Radiation force=momentum transferred per sec by electromagnetic wave to the mirror

$$= \frac{2S_{av}A}{c} = \frac{2 \times (10) \times (20 \times 10^{-4})}{(3 \times 10^{8})}$$

$$= 1.33 \times 10^{-10}\ \text{N}$$

$$= \frac{2S_{av}A}{c} = \frac{2 \times (10) \times (20 \times 10^{-4})}{(3 \times 10^{8})}$$

$$= 1.33 \times 10^{-10}\ \text{N}$$

31. (a)

Using the relation

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

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

$$= \frac{9.3}{3 \times 10^{8}} = 3.1 \times 10^{-8}\ \text{T}$$

32. (a)

33. (b)

Radioactive source, X-ray tube, sodium vapour lamp, crystal oscillator

34. (a)

Use method of dimensions. Equating the dimensions of two sides we note the relation

35. (d)

On the basis of dual nature of light, Louis de-Broglie suggested that the dual nature is not only of light, but each moving material particle has the dual nature. He assumed a wave to be associated with each moving material particle which is called the matter wave. The wavelength of this wave is determined by the momentum of the particle. If p is the momentum of the particle, the wavelength of the wave associated with it is

$$\lambda = \frac{h}{p}$$

Where h is Plank's constant.

Since, it is given that, alpha, beta and gamma rays carry same momentum, so they will have same wavelength.

36. (b)

Velocity of photon in vacuum is constant for all frequencies

37. (c)

A changing electric field produces a changing magnetic field and $vice - versa$ which gives rise to a transverse wave known as Electromagnetic Wave. The time varying electric and magnetic fields are mutually perpendicular to each other and also perpendicular to the direction of propagation of this wave.

38. (d)

Energy of a photon $E = \frac{hc}{\lambda}$

$\therefore$ Wavelength $\lambda = \frac{hc}{E}$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{13.2 \times 10^{3} \times 1.6 \times 10^{-19}}$$

$$= 0.9375 \times 10^{-10}\ \text{m}$$

$$= 1\ \text{Å}$$

Wavelength range of X-rays is from 10^{-11} m to 10^{-8} m (0.1 Å to 100 Å).

Therefore, the given electromagnetic radiation belongs to the X-ray region of electromagnetic spectrum.

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39. (c)
Equation second shows that the electromagnetic wave travels along the positive x-axis

40. (b)

$$B = \frac{\mu_0}{4\pi}\frac{2i_D}{r} = \frac{\mu_0}{4\pi} \times \varepsilon_0 \frac{d\phi_E}{dt}$$
$$= \frac{\mu_0}{2\pi}\frac{2i_D}{r} = \frac{\mu_0}{4\pi}\frac{2}{r} \times \varepsilon_0 \frac{d\phi_E}{dt}$$
$$= \frac{\mu_0 \varepsilon_0 \pi r^2 dE}{2\pi r dt} = \frac{\mu_0 \varepsilon_0 r}{2}\frac{dE}{dt}$$

41. (b)
Temperatures range from an average of −51∘C(−60∘F;220 K) near the tropopause to an average of −15∘C(5.0∘F;260 K) near the mesosphere. Stratospheric temperatures also vary within the stratosphere as the seasons change, reaching particularly low temperatures in the polar night (winter).

42. (c)
$E = \frac{hc}{\lambda}$; minimum the wavelength, the maximum the energy of a λ ray. Therefore, rays have minimum wave length.

43. (d)

$$V = \frac{hc}{e\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19} \times 10^{-10}}$$
$$= 10{,}000 \text{ V}$$

44. (b)

$\psi_{(x,t)} = 10^3 \sin\pi(3 \times 10^6\, x - 9 \times 10^{14}\, t)$
$= 10^3 \sin 3 \times 10^6\, \pi(x - 3 \times 10^8\, t)$
Comparing it with the relation
$\psi_{(x,t)} = a \sin\frac{2\pi}{\lambda}(x - ct)$; We note that
$c = 3 \times 10^8 \text{ ms}^{-1}$

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