CHAPTER 8

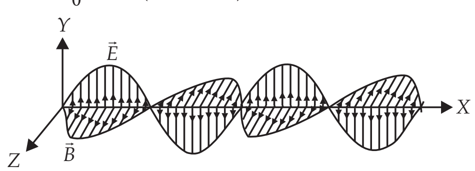
Electromagnetic Waves

Recap Notes

- **Electromagnetic (E.M.) waves** : E.M. waves are those waves in which there is a sinusoidal variation of electric and magnetic fields at right angle to each other as well as at right angle to the direction of wave propagation.
  - For a plane progressive electromagnetic wave propagating along + Z direction, the electric and magnetic fields can be written as

    $E = E_0 \sin(kz - \omega t)$

    $B = B_0 \sin(kz - \omega t)$



  - In electromagnetic wave, the electric and magnetic fields vary with space and time and have the same frequency and are in the same phase.
  - The amplitudes of electric and magnetic fields in free space, in electromagnetic waves are related by

    $E_0 = cB_0$ or $B_0 = \frac{E_0}{c}$
  - The speed of electromagnetic wave in free space is

    $c = \frac{E_0}{B_0} = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3 \times 10^8$ m/s

    where μ_0 and ε_0 are the permeability and permittivity of free space respectively.
  - The speed of electromagnetic wave in a medium is

    $v = \frac{1}{\sqrt{\mu\varepsilon}}$

    where μ and ε are permeability and permittivity of the medium respectively.

    $v = \frac{1}{\sqrt{\mu_0\mu_r\varepsilon_0\varepsilon_r}} = \frac{c}{\sqrt{\mu_r\varepsilon_r}}$
  - **Properties of electromagnetic waves**
    - These waves do not carry any charge.
    - These waves are not deflected by electric and magnetic fields.
    - They travel with the speed of light c (= 3×10^8 m s^{-1}) in vacuum.
    - The frequency of electromagnetic wave does not change when it goes from one medium to another but its wavelength changes.
    - These waves are transverse in nature, hence they can be polarised.
  - **Production of electromagnetic waves**
    - Maxwell showed that an electric charge oscillating harmonically with frequency υ produces electromagnetic waves of the same frequency.
    - An electric dipole is a basic source of electromagnetic waves.
  - **Energy density of electromagnetic waves**
    - Electromagnetic waves carry energy as they travel through space and this energy is equally shared by electric field and magnetic field of electromagnetic wave.
    - The energy density of the electric field is

      $u_E = \frac{1}{2}\varepsilon_0 E_{rms}^2$
    - The energy density of magnetic field is

      $u_B = \frac{1}{2}\frac{B_{rms}^2}{\mu_0}$

– Average energy density of electromagnetic wave is

$$<u> = \frac{1}{2}\varepsilon_0 E_{rms}^2 + \frac{1}{2\mu_0}B_{rms}^2$$

- **Intensity of electromagnetic wave :** It is defined as energy crossing per unit area per unit time perpendicular to the direction of propagation of electromagnetic wave. The intensity of electromagnetic wave is

$$I = <u> c = \frac{1}{2}\varepsilon_0 E_{rms}^2 c + \frac{B_{rms}^2}{2\mu_0}c$$

- **Momentum of electromagnetic wave**
  – An electromagnetic wave carries linear momentum.
  – Electromagnetic wave strikes the surface at normal incidence and transports a total energy U to the surface in a time t, if the surface absorbs all the incident energy, the total momentum p transported to the surface is

$$p = \frac{U}{c} \text{ (complete absorption)}$$

  – If the surface is a perfect reflector and incidence is normal then the momentum transported to the surface is

$$p = \frac{2U}{c} \text{ (complete reflection)}$$

- **Radiation pressure :** It is defined as the pressure exerted by the electromagnetic wave on a surface.
  - If I is the intensity of the incident electromagnetic radiation, then the radiation pressure for normal incidence is

$$P_{\text{radiation}} = \frac{I}{c} \text{ (perfectly absorbing surface)}$$

$$P_{\text{radiation}} = \frac{2I}{c} \text{ (perfectly reflecting surface)}$$

- **Electromagnetic spectrum :** The orderly distribution of electromagnetic radiations according to their wavelength or frequency is known as electromagnetic spectrum.

Type	Wavelength range	Frequency range (in Hz)	Production	Detection
Radio waves	> 0.1 m	$< 3 \times 10^9$	Rapid acceleration and deceleration of electrons in aerials	Receiver's aerials
Microwaves	0.1 m to 1 mm	3×10^8 to 3×10^{11}	Klystron valve or magnetron valve	Point contact diodes
Infra-red	1 mm to 700 nm	3×10^{11} to 4×10^{14}	Vibration of atoms and molecules	Thermopiles, Bolometer, Infrared photographic film
Visible light	700 nm to 400 nm	4×10^{14} to 8×10^{14}	Electrons in atoms emit light when they move from one energy level to a lower energy level	The eye, Photocells, Photographic film
Ultraviolet	400 nm to 1 nm	8×10^{14} to 8×10^{16}	Inner shell electrons in atoms moving from one energy level to a lower level	Photocells, Photographic film
X-rays	1 nm to 10^{-3} nm	1×10^{16} to 3×10^{21}	X-ray tubes or inner shell electrons	Photographic film, Geiger tubes
Gamma rays	< 10^{-3} nm	$> 3 \times 10^{21}$	Radioactive decay of the nucleus	Photographic film, Ionization chamber

Practice Time

OBJECTIVE TYPE QUESTIONS

Multiple Choice Questions (MCQs)

1. A plane electromagnetic wave travels in vacuum along z-direction. If the frequency of the wave is 40 MHz then its wavelength is

(a) 5 m (b) 7.5 m
(c) 8.5 m (d) 10 m

2. An electromagnetic wave of frequency υ = 3 MHz passes from vacuum into a dielectric medium with permittivity $\varepsilon = 4$. 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.

3. The ratio of contributions made by the electric field and magnetic field components to the intensity of an electromagnetic wave is

(a) $c : 1$ (b) $c^2 : 1$
(c) 1 : 1 (d) $\sqrt{c} : 1$

4. About 6% of the power of a 100 W light bulb is converted to visible radiation. The average intensity of visible radiation at a distance of 8 m is (Assume that the radiation is emitted isotropically and neglect reflection).

(a) 3.5×10^{-3} W m^{-2} (b) 5.1×10^{-3} W m^{-2}
(c) 7.4×10^{-3} W m^{-2} (d) 2.3×10^{-3} W m^{-2}

5. Which of the following rays is not an electromagnetic wave?

(a) X-rays (b) γ-rays
(c) β-rays (d) Heat rays

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. Which waves are used in sonography ?

(a) Microwaves (b) Infrared rays
(c) Radio waves (d) Ultrasonic waves

8. 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

9. 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

10. A plane electromagnetic wave of frequency 25 MHz travels in free space along x-direction. At a particular point in space and time, electric field E = 6.3 V m^{-1}. The magnitude of magnetic field B at this point is

(a) 1.2×10^{-6} T (b) 1.2×10^{-8} T
(c) 2.1×10^{-6} T (d) 2.1×10^{-8} T

11. A plane electromagnetic wave is incident on a material surface. The wave delivers momentum p and energy E. Then

(a) $p \neq 0, E \neq 0$ (b) $p = 0, E = 0$
(c) $p = 0, E \neq 0$ (d) $p \neq 0, E = 0$

12. 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}

13. 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.

14. The amplitude of the magnetic field of a harmonic electromagnetic wave in vacuum is B_0 = 510 nT. The amplitude of the electric field part of the wave is

(a) 120 N C^{-1} (b) 134 N C^{-1}
(c) 510 N C^{-1} (d) 153 N C^{-1}

15. The decreasing order of wavelength of infrared, microwave, ultraviolet and gamma rays is
(a) microwave, infrared, ultraviolet, gamma rays
(b) infrared, microwave, ultraviolet, gamma rays
(c) gamma rays, ultraviolet, infrared, microwaves
(d) microwaves, gamma rays, infrared, ultraviolet

16. If μ_0 be the permeability and k_0 be the dielectric constant of a medium, then its refractive index is given by
(a) $\frac{1}{\sqrt{\mu_0 k_0}}$ (b) $\frac{1}{\mu_0 k_0}$ (c) $\sqrt{\mu_0 k_0}$ (d) $\mu_0 k_0$

17. Which of the following statement is false for the properties of electromagnetic waves?
(a) Both electric and magnetic field vectors attain the maxima and minima at the same place and same time.
(b) The energy in electromagnetic wave is divided equally between electric and magnetic field vectors.
(c) Both electric and magnetic field vectors are parallel to each other and perpendicular to the direction of propagation of wave
(d) These waves do not require any material medium for propagation.

18. The source of electromagnetic waves can be charge, when
(a) moving with a constant velocity
(b) moving in a circular orbit
(c) falling in an electric field
(d) both (b) and (c)

19. An electromagnetic wave radiates outwards from a dipole antenna, with the amplitude of its electric field vector E_0. The electric field which transports significant energy from the source falls off as
(a) $\frac{1}{r^3}$ (b) $\frac{1}{r^2}$ (c) $\frac{1}{r}$ (d) r

20. The electric field associated with an electromagnetic wave in vacuum is given by $\vec{E} = 40\cos(kz - 6\times10^8 t)\hat{i}$, where E, z and t are in volt per meter, meter and second respectively. The value of wave vector k is
(a) $2\ \text{m}^{-1}$ (b) $0.5\ \text{m}^{-1}$ (c) $6\ \text{m}^{-1}$ (d) $3\ \text{m}^{-1}$

21. A microwave and an ultrasonic sound wave have the same wavelength. Their frequencies are in the ratio (approximately)
(a) 10^2 (b) 10^4 (c) 10^6 (d) 10^8

22. 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}

23. 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

24. The amplitude of an electromagnetic wave in vacuum is doubled with no other changes made to the wave. As a result of this doubling of the amplitude, which of the following statement is correct?
(a) The speed of wave propagation changes only
(b) The frequency of the wave changes only
(c) The wavelength of the wave changes only
(d) None of these.

25. The frequency of electromagnetic wave which is best suitable to observe a particle of radius 3×10^{-4} cm is of the order of
(a) 10^{15} Hz (b) 10^{11} Hz
(c) 10^{13} Hz (d) 10^{12} Hz

26. Frequency of radiations arising from two close energy levels in hydrogen, known as lamb shift is 1057 MHz. This frequency falls in which range of electromagnetic wave?
(a) Infrared rays (b) X-rays
(c) γ-rays (d) Radio waves

27. X-rays, gamma rays and microwaves travelling in vacuum have
(a) same wavelength but different velocities
(b) same frequency but different velocities
(c) same velocity but different wavelengths
(d) same velocity and same frequency

28. The electric field part of an electromagnetic wave in vacuum is $E = 3.1\,\text{N C}^{-1}\cos\left[(1.8\ \text{rad m}^{-1})y + (5.4\times10^8\ \text{rad s}^{-1})t\right]\hat{i}$. The wavelength of this part of electromagnetic wave is
(a) 1.5 m (b) 2 m (c) 2.5 m (d) 3.5 m

29. The ratio of amplitude of magnetic field to the amplitude of electric field for an electromagnetic wave propagating in vacuum is equal to
(a) the speed of light in vacuum
(b) reciprocal of speed of light in vacuum
(c) the ratio of magnetic permeability to the electric susceptibility of vacuum
(d) unity

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

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

$E_z = 0$. The wave is

(a) moving along x direction with frequency 10^6 Hz and wavelength 100 m
(b) moving along x direction with frequency 10^6 Hz and wavelength 200 m
(c) moving along $-x$ 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

31. 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^{-1} . At this point $\vec{B}$ is equal to

(a) $8.33\times10^{-8}\hat{k}$ T (b) $18.9\times10^{-8}\hat{k}$ T
(c) $2.1\times10^{-8}\hat{k}$ T (d) $2.1\times10^{-8}\hat{k}$ T

32. Which one of the following is the property of a monochromatic, plane electromagnetic wave in free space?

(a) Electric and magnetic fields have a phase difference of $\frac{\pi}{2}$.
(b) The energy contribution of both electric and magnetic fields are equal.
(c) The direction of propagation is in the direction of $\vec{B}\times\vec{E}$.
(d) The pressure exerted by the wave is the product of its speed and energy density.

33. An electromagnetic wave is propagating along x-axis. At $x = 1$ m and $t = 10$ s, its electric vector $|\vec{E}| = 6$ V/m then the magnitude of its magnetic vector is

(a) 2×10^{-8} T (b) 3×10^{-7} T
(c) 6×10^{-8} T (d) 5×10^{-7} T

34. An electromagnetic wave propagating along north has its electric field vector upwards. Its magnetic field vector point towards

(a) north (b) east
(c) west (d) downwards

35. The waves used by artificial satellites for communication is

(a) microwaves (b) infrared waves
(c) radio waves (d) X-rays

36. Assume a bulb of efficiency 2.5% as a point source. The peak values of electric and magnetic fields produced by the radiation coming from a 100 W bulb at a distance of 3 m is respectively

(a) 2.5 V m^{-1}, 3.6×10^{-8} T
(b) 4.2 V m^{-1}, 2.8×10^{-8} T
(c) 4.08 V m^{-1}, 1.36×10^{-8} T
(d) 3.6 V m^{-1}, 4.2×10^{-8} T

37. 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

38. The magnetic field of a beam emerging from a filter facing a flood light as given by $B = 12 \times 10^{-8} \sin(1.20 \times 10^7 z - 3.60 \times 10^{15} t)\ T$. The average intensity of the beam is

(a) 1.71 W m^{-2} (b) 2.1 W m^{-2}
(c) 3.2 W m^{-2} (d) 2.9 W m^{-2}

39. 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 J m^{-3})

(a) 13.29×10^{-12} (b) 8.85×10^{-12}
(c) 17.72×10^{-12} (d) 4.43×10^{-12}

40. Radio waves diffract around buildings, although light waves do not. The reason is that radio waves

(a) travel with speed larger than c
(b) have much larger wavelength than light
(c) are not electromagnetic waves
(d) none of these

Case Based MCQs

Case I : Read the passage given below and answer the following questions from 41 to 44.

Directions of Electromagnetic Waves

In an electromagnetic wave both the electric and magnetic fields are perpendicular to the direction of propagation, that is why electromagnetic waves are transverse in nature. Electromagnetic waves carry energy as they travel through space and this energy is shared equally by the electric and magnetic fields. Energy density of an electromagnetic waves is the energy in unit volume of the space through which the wave travels.

41. The electromagnetic 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) $\vec{B}\times\vec{E}$

42. Fundamental particle in an electromagnetic wave is

(a) photon (b) electron

(c) phonon (d) proton

43. 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

44. 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.

Case II : Read the passage given below and answer the following questions from 45 to 47.

Momentum and Pressure of an Electromagnetic Wave

An electromagnetic wave transports linear momentum as it travels through space. If an electromagnetic wave transfers a total energy U to a surface in time t, then total linear momentum delivered to the surface is $p = \frac{U}{c}$.

When an electromagnetic wave falls on a surface, it exerts pressure on the surface. In 1903, the American scientists Nichols and Hull succeeded in measuring radiation pressures of visible light where other had failed, by making a detailed empirical analysis of the ubiquitous gas heating and ballistic effects.

45. The pressure exerted by an electromagnetic wave of intensity I(W m^{-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

46. 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

47 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}) is

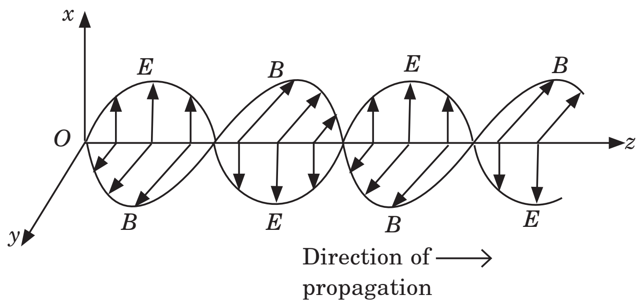
(a) 500 (b) 100

(c) $\frac{500}{3}$ (d) $\frac{250}{3}$

Case III : Read the passage given below and answer the following questions from 48 to 50.

Oscillating Charge

A stationary charge produces only an electrostatic field while a charge in uniform motion produces a magnetic field, that does not change with time. An oscillating charge is an example of accelerating charge. It produces an oscillating magnetic field, which in turn produces an oscillating electric fields and so on. The oscillating electric and magnetic fields regenerate each other as a wave which propagates through space.



48 Magnetic field in a plane electromagnetic wave is given by $\vec{B} = B_0 \sin(kx + \omega t)\hat{j}$ T.

Expression for corresponding electric field will be (Where c is speed of light.)

(a) $\vec{E} = -B_0 c \sin(kx + \omega t)\hat{k}$ V/m

(b) $\vec{E} = B_0 c \sin(kx - \omega t)\hat{k}$ V/m

(c) $\vec{E} = \frac{B_0}{c} \sin(kx + \omega t)\hat{k}$ V/m

(d) $\vec{E} = B_0 c \sin(kx + \omega t)\hat{k}$ V/m

49 The electric field component of a monochromatic radiation is given by $\vec{E} = 2E_0\hat{i}\cos kz \cos\omega t$. Its magnetic field $\vec{B}$ is then given by

(a) $\frac{2E_0}{c}\hat{j}\cos kz \cos\omega t$ (b) $\frac{2E_0}{c}\hat{j}\sin kz \cos\omega t$

(c) $\frac{2E_0}{c}\hat{j}\sin kz \sin\omega t$ (d) $-\frac{2E_0}{c}\hat{j}\sin kz \sin\omega t$

50. A plane em wave of frequency 25 MHz travels in a free space along x-direction. At a particular point in space and time, $E = (6.3\,\hat{j})$ V/m. What is magnetic field at that time?

(a) 0.095 μT (b) 0.124 μT

(c) 0.089 μT (d) 0.021 μT

Assertion & Reasoning Based MCQs

For question numbers 51-60, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

(a) Both A and R are true and R is the correct explanation of A

(b) Both A and R are true but R is NOT the correct explanation of A

(c) A is true but R is false

(d) A is false and R is also false

51. Assertion (A) : Radio waves cannot be diffracted by the buildings.

Reason (R) : The wavelength of radio waves is very small.

52. Assertion : Only microwaves are used in radar.

Reason : Because microwaves have very small wavelength.

53. Assertion (A) : The electric field and magnetic field have equal average values in linearly polarised plane em wave.

Reason (R) : The electric energy and magnetic energy have equal average values in linearly polarised plane em wave.

54. Assertion (A) : Light can travel in vacuum whereas sound cannot do so.

Reason (R) : Light has an electromagnetic wave nature whereas sound is mechanical wave.

55. Assertion (A) : The microwaves are better carriers of signals than radio waves.

Reason (R) : The electromagnetic waves do not required any material medium for propagation.

56. Assertion (A) : Velocity of light is constant in all media.

Reason (R) : Light is an electromagnetic wave which has constant velocity in all media.

57. Assertion (A) : X-rays in vacuum travel faster than light waves in vacuum.

Reason (R) : The energy of X-rays photon is less than that of light photon.

58. Assertion (A) : Electromagnetic waves exert pressure called radiation pressure.

Reason (R) : Electromagnetic waves carries energy.

59. Assertion (A) : Infrared waves sometimes referred as heat waves.

Reason (R) : Infrared waves heat up the earth surface.

60. Assertion (A) : X-ray astronomy is possible only from satellites orbiting the earth.

Reason (R) : Efficiency of X-rays telescope is large as compared to any other telescope.

SUBJECTIVE TYPE QUESTIONS

Very Short Answer Type Questions (VSA)

1. To which part of the electromagnetic spectrum does a wave of frequency 5×10^{19} Hz belong?

2. How are radio waves produced?

3. Welders wear special goggles or face masks with glass windows to protect their eyes from electromagnetic radiations. Name the radiations and write the range of their frequency.

4. The small ozone layer on top of the stratosphere is crucial for human survival. Why?

5. Write two uses of microwaves.

6. If the Earth did not have atmosphere, would its average surface temperature be higher or lower than what it is now? Explain.

7. An e.m. wave exerts pressure on the surface on which it is incident. Justify.

8. Do electromagnetic waves carry energy and momentum?

9. How is the speed of em-waves in vacuum determined by the electric and magnetic fields?

10. In which directions do the electric and magnetic field vectors oscillate in an electromagnetic wave propagating along the *x*-axis ?

Short Answer Type Questions (SA-I)

11. Illustrate by giving suitable examples, how you can show that electromagnetic waves carry both energy and momentum.

12. A plane electromagnetic wave travels in vacuum along z-direction. What can you say about the direction of electric and magnetic field vectors?

13. An *e.m.* wave is travelling in a medium with a velocity $\vec{v} = v\hat{i}$. Draw a sketch showing the propagation of the *e.m.* wave, indicating the direction of the oscillating electric and magnetic fields.

14. Name the physical quantity which remains same for microwaves of wavelength 1 mm and UV radiations of 1600 Å in vacuum.

15. 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 which region?

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

17. The electric field in an electromagnetic wave is given by $E = (50\ \text{N C}^{-1})\sin \omega(t - x/c)$. Find the energy contained in a cylinder of cross-section 10 cm^2 and length 50 cm along the x-axis.

18. How are infrared waves produced? Why are these referred as heat waves? Write their one important use?

19. Explain briefly how electromagnetic waves are produced by an oscillating charge. How is the frequency of the *e.m.* waves produced related to that of the oscillating charge?

20. Identify the electromagnetic waves whose wavelengths vary as

(a) $10^{-11}\ \text{m} < \lambda < 10^{-14}\ \text{m}$

(b) $10^{-4}\ \text{m} < \lambda < 10^{-6}\ \text{m}$

Write one use of each.

Short Answer Type Questions (SA-II)

21. Name the constituent radiation of electromagnetic spectrum which is used for

(i) aircraft navigation.

(ii) studying crystal structure.

Write the frequency range for each.

22. Gamma rays and radio waves travel with the same velocity in free space. Distinguish between them in terms of their origin and the main application.

23. Identify the part of the electromagnetic spectrum used in (i) radar and (ii) eye surgery. Write their frequency range.

24. (i) Which segment of electromagnetic waves has highest frequency? How are these waves produced? Give one use of these waves.

(ii) Which *e.m. waves* lie near the high frequency end of visible part of *e.m.* spectrum? Give its one use. In what way this component of light has harmful effects on humans?

25. Name the parts of the electromagnetic spectrum which is

(a) suitable for radar systems used in aircraft navigation.

(b) used to treat muscular strain.

(c) used as a diagnostic tool in medicine.

Write in brief, how these waves can be produced.

26. Prove that the average energy density of the oscillating electric field is equal to that of the oscillating magnetic field.

27. Name the types of *em* radiations which

(i) are used in destroying cancer cells,

(ii) cause tanning of the skin and (iii) maintain the earth's warmth.

Write briefly a method of producing any one of these waves.

28. (a) Arrange the following electromagnetic waves in the descending order of their wavelengths :

(i) Microwaves

(ii) Infra-red rays

(iii) Ultra-violet-radiation

(iv) Gamma rays

(b) Write one use each of any two of them.

29. (a) Optical and radio telescopes are built on the ground but X-ray astronomy is possible only from satellites orbiting the earth. Why?

(b) The small ozone layer on top of the stratosphere is crucial for human survival. Why?

30. Suppose that the electric field part of an electromagnetic wave in vacuum is

$$\vec{E} = (3.1 \text{ N/C}) \cos[(1.8 \text{ rad/m})\, y + (5.4 \times 10^8 \text{ rad/s})t]\hat{t}$$

(a) What is the direction of propagation?

(b) What is the wavelength λ?

(c) What is the frequency ν?

31. (a) When the oscillating electric and magnetic fields are along the x-and y-direction respectively.

(i) point out the direction of propagation of electromagnetic wave.

(ii) express the velocity of propagation in terms of the amplitudes of the oscillating electric and magnetic fields.

(b) How do you show that the e.m. wave carries energy and momentum?

Long Answer Type Questions (LA)

32. Answer the following questions:

(a) Show, by giving a simple example, how *e.m.* waves carry energy and momentum.

(b) How are microwaves produced? Why is it necessary in microwave ovens to select the frequency of microwaves to match the resonant frequency of water molecules?

(c) Write two important uses of infrared waves.

33. State clearly how a microwave oven works to heat up a food item containing water molecules. Why are microwaves found useful for the radar systems in aircraft navigation?

34. The intensity of light ranges from about $\frac{1 \text{ W}}{\text{m}^2}$ for a candle to about 30 μW/m^2 for a modest size laser. A particular laser produces a power 4 W in a beam 0.4 mm in diameter.

(a) What is its average intensity?

(b) Find the peak electric field of the laser light.

(c) Find the peak magnetic field of the laser light.

(d) If the laser beam is aimed upward to levitate a 20 mm diameter sphere, what is the maximum mass of this sphere. Assume the sphere is perfectly reflecting.

35. A plane EM wave travelling along z-direction is described by $\vec{E} = E_0 \sin(kz - \omega t)\hat{i}$ and $B = B_0 \sin(kz - \omega t)\hat{j}$. Show that

(a) The average energy density of the wave is given by $u_{av} = \frac{1}{4}\varepsilon_0 E_0^2 + \frac{1}{4}\frac{B_0^2}{\mu_0}$.

(b) The time averaged intensity of the wave is given by $I_{av} = \frac{1}{2}c\varepsilon_0 E_0^2$.

ANSWERS

OBJECTIVE TYPE QUESTIONS

1. **(b) :** Wavelength, $\lambda = \frac{c}{\upsilon} = \frac{3 \times 10^8 \text{ m s}^{-1}}{40 \times 10^6 \text{ s}^{-1}} = 7.5$ m

2. **(d) :** The frequency of electromagnetic wave remains unchanged but the wavelength of electromagnetic wave changes when it passes from one medium to another.

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

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

$$\therefore \quad \frac{c}{v} = \sqrt{\frac{\varepsilon}{\varepsilon_0}} = \sqrt{\frac{4}{1}} = 2$$

$$\frac{c}{v} = \frac{\upsilon\lambda}{\upsilon\lambda'} = \frac{\lambda}{\lambda'} = 2 \quad \text{or} \quad \lambda' = \frac{\lambda}{2}$$

3. **(c) :** Intensity of electromagnetic wave, $I = U_{av}\, c$

In terms of electric field, $U_{av} = \frac{1}{2}\varepsilon_0 E_0^2$

In terms of magnetic field, $U_{av} = \frac{1}{2}\frac{B_0^2}{\mu_0}$

Now U_{av} electric field $= \frac{1}{2}\varepsilon_0 E_0^2$

$$= \frac{1}{2}\varepsilon_0 (cB_0)^2 = \frac{1}{2}\varepsilon_0 \times \frac{1}{\mu_0 \varepsilon_0} B_0^2 \qquad \left(\because \frac{E_0}{B_0} = c\right)$$

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

(due to magnetic field)

Thus the energy in electromagnetic wave is divided equally between electric field vector and magnetic field vector. Therefore, the ratio of contributions by the electric field and magnetic field components to the intensity of electromagnetic wave is 1 : 1.

4. (c) : Here, power of bulb = 100 W

As intensity, $I = \dfrac{\text{Power of visible light}}{\text{area}}$

$= \dfrac{100 \times 6/100}{4\pi(8)^2} = 7.4 \times 10^{-3}$ W m^{-2}

5. (c)

6. (a) : Here, $\upsilon_1 = 7.5$ MHz, $\upsilon_2 = 12$ MHz

$\therefore \quad \lambda_1 = \dfrac{c}{\upsilon_1} = \dfrac{3\times10^8}{7.5\times10^6} = 40\,\text{m}$

and $\quad \lambda_2 = \dfrac{c}{\upsilon_2} = \dfrac{3\times10^8}{12\times10^6} = 25\,\text{m}$

7. (d)

8. (b) : The total energy falling on the surface is
$U = 18 \times 20 \times (30 \times 60) = 6.48 \times 10^5$ J
Therefore, the total momentum delivered (for complete absorption is)

$p = \dfrac{U}{c} = \dfrac{6.48\times10^5}{3\times10^8} = 2.16 \times 10^{-3}$ kg m s^{-1}

The average force exerted on the surface is

$F = \dfrac{p}{t} = \dfrac{2.16\times10^{-3}}{0.18\times10^4} = 1.2 \times 10^{-6}$ N

9. (d) : Microwaves are used to cook food. Microwave oven is a domestic application of these waves.

10. (d) : As, $B = \dfrac{E}{c} = \dfrac{6.3}{3\times10^8} = 2.1\times10^{-8}$ T

11. (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 $E \neq 0$.

12. (a) : $P = \dfrac{I}{c} = \dfrac{0.5}{3 \times 10^8}$

$= 0.166 \times 10^{-8}$ N m^{-2}

13. (c) : Here, $E = 11$ eV $= 11 \times 1.6 \times 10^{-19}$ J $= h\upsilon$

$\therefore \quad \upsilon = \dfrac{11\times1.6\times10^{-19}}{h}$

$= \dfrac{11\times1.6\times10^{-19}}{6.62\times10^{-34}} = 2.6\times10^{15}$ Hz

This frequency radiation belongs to ultraviolet region.

14. (d) : Here, $B_0 = 510$ nT $= 510 \times 10^{-9}$ T
$E_0 = cB_0 = 3 \times 10^8 \times 510 \times 10^{-9} = 153$ N C^{-1}

15. (a)

16. (c) : Refractive index of medium is

$\mu = \dfrac{c}{\upsilon}$, where $c = \dfrac{1}{\sqrt{\mu_0 k_0}}$

and $\quad \upsilon = \dfrac{1}{\sqrt{\mu_0 k_0 \mu_r k_r}}$

$\therefore \quad \mu = \dfrac{1/\sqrt{\mu_0 k_0}}{1/\sqrt{\mu_0 k_0 \mu_r k_r}} = \sqrt{\mu_r k_r}$

Given $\mu_r = \mu_0$ and $k_r = k_0$ then $\mu = \sqrt{\mu_0 k_0}$

17. (c) : In an electromagnetic wave both electric and magnetic vectors are perpendicular to each other as well as perpendicular to the direction of propagation of wave.

18. (d) : An electromagnetic wave can be produced by accelerated or oscillating charge.
In options (b) and (c), the charge is in accelerated state, hence will be a source of electromagnetic waves.

19. (c) : From a dipole antenna, the electromagnetic waves are radiated outwards. The amplitude of electric field vector E_0 which transports significant energy from the source falls off intensity inversely as the distance r from the antenna *i.e.*, $E_0 \propto \dfrac{1}{r}$.

20. (a) : Compare the given equation with
$E = E_0\cos(kz - \omega t)$
We get, $\omega = 6 \times 10^8$ s^{-1}

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

21. (c) : Frequency of microwaves, $\upsilon_m \approx 10^{11}$ Hz
Frequency of ultrasonic sound waves, $\upsilon_u \approx 10^5$ Hz

$\therefore \quad \dfrac{\upsilon_m}{\upsilon_u} = \dfrac{10^{11}}{10^5} = 10^6$

22. (d) : As $E = \dfrac{hc}{\lambda}$

$= \dfrac{6.6\times10^{-34}\times3\times10^8}{2\times10^{-2}} = 9.9\times10^{-24}$ J

$= \dfrac{9.9\times10^{-24}}{1.6\times10^{-19}}\ \text{eV} = 6.2\times10^{-5}\ \text{eV}$

23. (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.

24. (d) : Velocity of electromagnetic wave

$$c=\frac{1}{\sqrt{\mu_0\,\varepsilon_0}}=3\times10^8\text{ m s}^{-1}$$

It is independent of amplitude, frequency and wavelength of electromagnetic wave.

25. (a) : Let λ be the radius of the particle then
$\lambda = 3\times10^{-4}\times10^{-2}\text{ m} = 3\times10^{-6}\text{ m}$

Frequency of electromagnetic wave, $\upsilon=\frac{c}{\lambda}=\frac{3\times10^8}{3\times10^{-6}}=10^{14}$

Thus to observe the particle, the frequency of wave should be more than 10^{14} *i.e* 10^{15} Hz or smaller value of wavelength.

26. (d) : This given frequency corresponds to the radio waves *i.e* short wavelength or high frequency.

27. (c) : In vacuum X-rays, gamma rays and microwaves travel with same velocity, *i.e.*, with the velocity of light c (= 3×10^8 m s^{-1}) but have different wavelengths.

28. (d) : Given

$E = 3.1\text{ N C}^{-1}\cos[(1.8\text{ rad m}^{-1})y+(5.4\times10^8\text{ rad s}^{-1})t]\,\hat{i}$ ...(i)

Camparing (i) with the equation

$E = E_0\cos(ky+\omega t)$ ...(ii)

We get, $k = 1.8$ rad m^{-1},

$E_0 = 3.1$ N C^{-1}, $c = 3\times10^8$ m s^{-1}, $\omega = 5.4\times10^8$ rad s^{-1}

Now, $\lambda=\frac{2\pi}{k}=\frac{2\times22}{1.8\times7}=3.5\text{ m}$

29. (b) : The amplitudes of electric field and magnetic field for an electromagnetic wave propagating in vacuum are related as $E_0 = B_0c$

where c is the speed of light in vacuum.

$\therefore\quad \frac{B_0}{E_0}=\frac{1}{c}$

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

$E_z = 0$, $E_x = 0$

The wave is moving in the positive direction of x.

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

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

$2\pi\upsilon = 2\pi\times10^6 \Rightarrow \upsilon = 10^6$ Hz

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

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

31. (c) : Here, $\vec{E}=6.3\,\hat{j}\text{ V m}^{-1}$

The magnitude of $\vec{B}$ is

$B=\frac{E}{c}=\frac{6.3\text{ V m}^{-1}}{3\times10^8\text{ m s}^{-1}}=2.1\times10^{-8}\text{ T}$

$\vec{E}$ is along y-direction and the wave propagates along x-axis. Therefore, $\vec{B}$ should be in a direction perpendicular to both x and y-axis. Using vector algebra $\vec{E}\times\vec{B}$ should be along x-direction.

Since $(+\hat{j})\times(+\hat{k})=\hat{i}$, $\vec{B}$ is along z-direction.

Thus, $\vec{B}=2.1\times10^{-8}\,\hat{k}\text{ T}$

32. (b) : In electromagnetic wave, electric and magnetic fields are in phase.

Electromagnetic wave carry energy as they travel through space and this energy is shared equally by electric and magnetic fields.

The direction of the propagation of electromagnetic wave is the direction of $\vec{E}\times\vec{B}$.

The pressure exerted by the wave is equal to its energy density.

33. (a) : Here, $|\vec{E}| = 6$ V/m

The magnitude of magnetic vector is

$$|\vec{B}|=\frac{|\vec{E}|}{c}=\frac{6\text{ V/m}}{3\times10^8\text{ m/s}}=2\times10^{-8}\text{ T}$$

34. (b)

35. (a) : In artificial satellite microwaves are used for communication.

36. (c) : Here intensity, $I=\frac{\text{power}}{\text{area}}$

$$=\frac{100\times2.5}{4\pi(3)^2\times100}=\frac{2.5}{36\pi}\text{ W m}^{-2}$$

Half of this intensity belongs to electric field and half of that to magnetic field.

$\therefore\quad \frac{I}{2}=\frac{1}{4}\varepsilon_0E_0^2c$

or $\quad E_0=\sqrt{\frac{2I}{\varepsilon_0c}}=\sqrt{\frac{2\times\frac{2.5}{36\pi}}{\frac{1}{4\pi\times9\times10^9}\times3\times10^8}}=4.08\text{ V m}^{-1}$

$\therefore\quad B_0=\frac{E_0}{c}=\frac{4.08}{3\times10^8}=1.36\times10^{-8}\text{ T}$

37. (d) : Given : $E = 13.2$ keV

$$\lambda(\text{in Å})=\frac{hc}{E(\text{in eV})}=\frac{12400}{13.2\times10^3}=0.939\text{ Å}\approx1\text{ Å}$$

X-rays cover wavelengths ranging from about 10^{-8} m (10 nm) to 10^{-13} m (10^{-4} nm).

An electromagnetic radiation of energy 13.2 keV belongs to X-ray region of electromagnetic spectrum.

38. (a) : Here, $B = 12 \times 10^{-8}$ sin $(1.20 \times 10^{7} z - 3.6 \times 10^{15} t)$ T

Comparing it with, $B = B_0 \sin(kz - \omega t)$,
we have $B_0 = 12 \times 10^{-8}$ T

$$I_{av} = \frac{1}{2}\frac{B_0^2 c}{\mu_0}$$

$$= \frac{1}{2} \times \frac{(12\times10^{-8})^2 \times 3\times10^8}{4\pi\times10^{-7}}$$

$= 1.71$ W m^{-2}

39. (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

$$u_B = \frac{1}{4}\frac{B_0^2}{\mu_0}$$

$$= \frac{1}{4}\frac{E_0^2}{\mu_0 c^2} \qquad \left(\because \quad B_0 = \frac{E_0}{c}\right)$$

$$= \frac{1}{4}\varepsilon_0 E_0^2 \qquad \left(\because \quad c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}\right)$$

$$= \frac{1}{4} \times 8.854 \times 10^{-12} \times (2)^2$$

$= 8.854 \times 10^{-12}$ J m^{-3}
$\approx 8.85 \times 10^{-12}$ J m^{-3}

40. (b) : The wavelength of radiowaves being much larger than light, has a size comparable to those of buildings, hence diffract from them.

41. (b) : Electromagnetic waves propagate in the direction of $\vec{E} \times \vec{B}$.

42. (a) : Photon is the fundamental particle in an electromagnetic wave.

43. (c) : Frequency υ remains unchanged when a wave propagates from one medium to another. Both wavelength and velocity get changed.

44. (c) : The electric and magnetic fields of an electromagnetic wave are in phase and perpendicular to each other.

45. (c) : Pressure exerted by an electromagnetic radiation,

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

46. (d) : $P_{\text{rad}} = \frac{\text{Energy flux}}{\text{Speed of light}} = \frac{18 \text{ W/cm}^2}{3\times10^8 \text{ m/s}}$

$$= \frac{18\times10^4 \text{ W/m}^2}{3\times10^8 \text{ m/s}} = 6\times10^{-4} \text{ N/m}^2$$

47. (b) : Intensity of EM wave is given by $I = \dfrac{P}{4\pi R^2}$

$$V_{av} = \frac{1}{2}\varepsilon_0 E_0^2 \times c$$

$$\Rightarrow E_0 = \sqrt{\frac{P}{2\pi R^2 \varepsilon_0 c}} = \sqrt{\frac{1500}{2\times3.14(3)^2\times8.85\times10^{-12}\times3\times10^8}}$$

$$= \sqrt{10{,}000} = 100 \text{ V m}^{-1}$$

48. (d) : Given : $\vec{B} = B_0 \sin(kx + \omega t)\hat{j}$ T

The relation between electric and magnetic field is,

$c = \frac{E}{B}$ or $E = cB$

The electric field component is perpendicular to the direction of propagation and the direction of magnetic field. Therefore, the electric field component along z-axis is obtained as

$\vec{E} = cB_0 \sin(kx + \omega t)\hat{k}$ V/m

49. (c) : $\frac{dE}{dz} = -\frac{dB}{dt}$

$$\frac{dE}{dz} = -2E_0 k \sin kz \cos\omega t = -\frac{dB}{dt}$$

$$dB = +2E_0 k \sin kz \cos\omega t\, dt$$

$$B = +2E_0 k \sin kz \int \cos\omega t\, dt = +2E_0 \frac{k}{\omega} \sin kz \sin\omega t$$

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

$$B = \frac{2E_0}{c}\sin kz \sin\omega t \quad \therefore \quad \vec{B} = \frac{2E_0}{c}\sin kz \sin\omega t\,\hat{j}$$

E is along y-direction and the wave propagates along x-axis.
$\therefore$ B should be in a direction perpendicular to both x-and y-axis.

50. (d) : Here, $E = 6.3\hat{j}$; $c = 3 \times 10^8$ m/s

The magnitude of B is

$$B_z = \frac{E}{c} = \frac{6.3}{3\times10^8} = 2.1\times10^{-8} \text{ T} = 0.021\ \mu\text{T}$$

51. (d) : For wave to suffer diffraction, the wavelength should be of the order of size of the obstacle. The wavelength of radio waves (short radio waves) is order of the size of the building and the other obstacles coming in their path and hence they easily get diffracted.

52. (a) : In a radar, a beam signal is needed in particular direction which is possible if wavelength of wave is very small. Since the wavelength of microwaves is a few millimeter, hence they are used in radar.

53. (b) : In case of a linearly polarised plane electromagnetic wave, the average values of electric field and magnetic field are equal and average values of electric energy and magnetic energy are also equal.

54. (a) : Light being electromagnetic wave do not require any material medium for its propagation. Hence light can travel in vacuum. On the other hand sound is a mechanical wave and requires a material medium for its propagation. Hence sound cannot travel in vacuum.

55. (b) : Microwaves are the electromagnetic waves of wavelength of the order of a few millimetres, which is less than those of T.V. signals. On account of smaller wavelength, the microwaves can be transmitted as beam signals in a particular direction and are much better than radiowaves because microwaves do not spread or bend around the corners of any obstacle coming in their way. Therefore microwaves are better carriers of signals than radiowaves.

56. (d) : Velocity of light has different values in different media.
It depends on the refractive index of the medium. Related by formula

$$v_{\text{medium}} = \frac{\text{velocity in vacuum}}{\text{refractive index of medium}}$$

57. (d) : All electromagnetic waves including X-rays travels with same velocity in vacuum. The energy of X-rays is greater than energy of the light because energy is inversely proportional to wavelength ($E = hc/\lambda$) and wavelength of X-rays are smaller than light waves.

58. (b) : Electromagnetic waves transport linear momentum as well as energy. When electromagnetic waves strike a surface, a pressure is exerted on the surface. If the intensity of wave is I, the radiation pressure P (force per unit area) exerted on the perfectly absorbing surface is $P = I/c$.

59. (b) : Infrared waves are sometimes called heat waves. This is because water molecules present in most materials readily absorb infrared waves. After absorption, their thermal motion increases, that is, they heat up and heat their surroundings.

60. (c) : The earth's atmosphere is transparent to visible light and radio waves, but absorbs X-rays. Therefore X-rays telescope cannot be used on earth surface.

SUBJECTIVE TYPE QUESTIONS

1. X-rays.

2. Radio waves are the electromagnetic waves of frequency ranging from 500 KHz to about 1000 MHz. These waves are produced by oscillating electric circuits having inductor and capacitor.

3. Ultraviolet radiations produced during welding are harmful to eyes. Special goggles or face masks are used to protect eyes from UV radiations. UV radiations have a range of frequency between 10^{14} Hz – 10^{16} Hz.

4. The small ozone layer on the top of the atmosphere is crucial for human survival because it absorbs harmful ultraviolet radiations present in sunlight and prevents it from reaching the earth's surface. These radiations can penetrate our skin and can cause harmful diseases like skin cancer etc.

5. Uses of microwaves :

(i) In long distance communication

(ii) In radar systems used in aircraft navigation

6. If the Earth did not have atmosphere, then there would be absence of green house effect of the atmosphere. Due to this reason, the temperature of the earth would be lower than what it is now.

7. An *e.m.* wave carries momentum with itself and given by

$$p = \frac{\text{Energy of wave } (U)}{\text{Speed of the wave } (c)}$$

When it is incident upon a surface it exerts pressure on it.

8. Yes, electromagnetic waves carry energy and momentum.

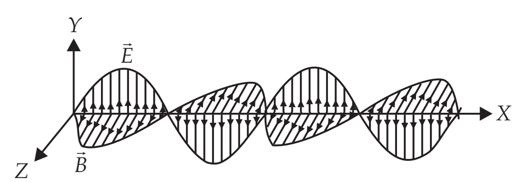
9. The speed of em-waves in vacuum determined by the electric (E_0) and magnetic fields (B_0) is, $c = \frac{E_0}{B_0}$.

10. When an electromagnetic wave is propagating along the *x*-axis then, electric field vector oscillates in *y*-axis and magnetic field vector oscillates in *z*-axis.

11. Electromagnetic waves like other waves carry energy and momentum as they travel through empty space. If light didn't carry energy and momentum, it wouldn't be able to heat stuff up or generate photocurrent in photocells.

12. The electric and magnetic field vectors $\vec{E}$ and $\vec{B}$ are perpendicular to each other and also perpendicular to the direction of propagation of the electromagnetic wave. If a plane electromagnetic wave is propagating along the *z*-direction, then the electric field is along *x*-axis, and magnetic field is along *y*-axis.

13. In figure the velocity of propagation of *e.m.* wave is along *X*-axis $\vec{v} = v\hat{i}$ and electric field $\vec{E}$ along *Y*-axis and magnetic field $\vec{B}$ along *Z*-axis.



14. The speed in vacuum (*i.e.*, $c = 3 \times 10^8$ m s^{-1}) remains same for both the given wavelengths. It is because both microwaves and UV rays are electromagnetic waves.

15. Here, $E = 11$ eV $= 11 \times 1.6 \times 10^{-19}$ J $= h\upsilon$

$$\therefore \quad \upsilon = \frac{11 \times 1.6 \times 10^{-19}}{h} = \frac{11 \times 1.6 \times 10^{-19}}{6.62 \times 10^{-34}} = 2.6 \times 10^{15} \text{ Hz}$$

This frequency belongs to ultraviolet region.

16. Electric field intensity on a surface due to the incident radiation is

$$E = \frac{U}{At} = \frac{P}{A} \qquad \left(\because \frac{U}{t} = P\right)$$

As, $E \propto P$ (for the given area of the surface)

$$\therefore \quad \frac{E'}{E} = \frac{P'}{P} = \frac{50}{100} = \frac{1}{2}$$

$$E' = \frac{E}{2}$$

17. The energy density is

$$u_{av} = \frac{1}{2}\varepsilon_0 E_0^2 = \frac{1}{2} \times (8.85 \times 10^{-12}) \times (50)^2 = 1.1 \times 10^{-8} \text{ J m}^{-3}$$

The volume of the cylinder is $V = 5 \times 10^{-4}$ m^3

The energy contained in cylinder is

$U = (1.1 \times 10^{-8} \text{ J m}^{-3}) \times (5 \times 10^{-4} \text{ m}^3) = 5.5 \times 10^{-12}$ J.

18. Infra red waves are produced by hot bodies and molecules. They are produced due to the de-excitation of atoms.

Infrared waves incident on a substance increase the internal energy and hence the temperature of the substance. That is why they are called heat waves.

Infra red radiations play an important role in maintaining the earth's warmth or average temperature through the greenhouse effect.

19. An oscillating or accelerated charge is supposed to be source of an electromagnetic wave. An oscillating charge produces an oscillating electric field in space which further produces an oscillating magnetic field which in turn is a source of electric field. These oscillating electric and magnetic field hence, keep on regenerating each other and an electromagnetic wave is produced.

The frequency of *e.m.* wave = Frequency of oscillating charge.

20. (a) Gamma rays lie between 10^{-11} m to 10^{-14} m.

These rays are used in radiotherapy to treat certain cancers and tumors.

(b) Infrared waves lie between 10^{-4} m to 10^{-6} m. These waves are used in taking photographs during conditions of fog, smoke etc., as these waves are scattered less than visible rays.

21. (i) Microwaves are used in radar system for aircraft navigation. The frequency range is 3×10^8 Hz to 3×10^{11} Hz.

(ii) X-rays are used for studying crystals structure of solids. Their frequency range is 3×10^{16} Hz to 3×10^{21} Hz.

22. Gamma rays : These rays are of nuclear origin and are produced in the disintegration of radioactive atomic nuclei and in the decay of certain subatomic particles. They are used in the treatment of cancer and tumours.

Radio waves : These waves are produced by the accelerated motion of charges in conducting wires or oscillating electric circuits having inductor and capacitor. These are used in satellite, radio and television communication

23.

	Uses	Part of electromagnetic spectrum	Frequency range
(i)	In radar system	Microwaves	3×10^8 Hz to 3×10^{11} Hz
(ii)	In eye surgery	Ultraviolet	8×10^{14} Hz to 8×10^{16} Hz

24. (i) Gamma rays has the highest frequency in the electromagnetic waves. These rays are of the nuclear origin and are produced in the disintegration of radioactive atomic nuclei and in the decay of certain subatomic particles. They are used in the treatment of cancer and tumours.

(ii) Ultraviolet rays lie near the high-frequency end of visible part of *e.m.* spectrum. These rays are used to preserve food stuff. The harmful effect from exposure to ultraviolet (UV) radiation can be life threatening, and include premature aging of the skin, suppression of the immune systems, damage to the eyes and skin cancer.

25. (a) Microwaves are suitable for radar systems used in aircraft navigation.

These waves are produced by special vacuum tubes, namely klystrons, magnetrons and Gunn diodes.

(b) Infra-red waves are used to treat muscular pain. These waves are produced by hot bodies and molecules.

(c) X-rays are used as a diagnostic tool in medicine. These are produced when high energy electrons are stopped suddenly on a metal of high atomic number.

26. In an electromagnetic wave, both E and B fields vary sinusoidally in space and time. The average energy density u of an e.m. wave can be obtained by replacing E and B by their rms value

$$u = \frac{1}{2}\varepsilon_0 E_{rms}^2 + \frac{1}{2\mu_0} B_{rms}^2 \text{ or } u = \frac{1}{4}\varepsilon_0 E_0^2 + \frac{1}{4\mu_0} B_0^2$$

$$\left[\because E_{rms} = \frac{E_0}{\sqrt{2}}, B_{rms} = \frac{B_0}{\sqrt{2}}\right]$$

Moreover, $E_0 = cB_0$ and $c^2 = \frac{1}{\mu_0 \varepsilon_0}$, therefore

$$u_E = \frac{1}{4}\varepsilon_0 E_0^2 = \frac{1}{4}\varepsilon_0 (cB_0)^2$$

$$u_E = \frac{1}{4}\varepsilon_0 \cdot \frac{B_0^2}{\mu_0 \varepsilon_0} = \frac{1}{4\mu_0} B_0^2 = u_B$$

27. (i) Gamma rays

(ii) UV rays

(iii) Infra-red radiations

Infra-red waves are produced by hot bodies and molecules. Infra-red waves are referred to as heat waves, because water molecules present in most materials readily absorb infra-red waves (many other molecules, for example, CO_2, NH_3 also absorb infra-red waves). After absorption, their thermal motion increases, that is they heat up and heat their surroundings.

28. (a) Descending order of wavelengths for given electromagnetic waves is:

Microwaves ($10^{-3} - 10^{-1}$) m

Infra-red rays ($7.5 \times 10^{-7} - 10^{-3}$) m

Ultra-violet radiation ($10^{-9} - 4 \times 10^{-7}$) m

Gamma rays ($< 10^{-12}$) m

(b) Microwaves :

Frequency range $\rightarrow 3 \times 10^8$ Hz -3×10^{11} Hz. These are suitable for the radar system, used in aircraft navigation.

Gamma rays :

Frequency range $\rightarrow > 3 \times 10^{21}$ Hz.

These wave are used for the treatment of cancer cells.

29. (a) The earth's atmosphere is transparent to visible light and radiowaves but it absorbs X-rays. X-ray astronomy is possible only from satellites orbiting the earth. These satellites orbit at a height of 36,000 km, where the atmosphere is very thin and X-rays are not absorbed.

(b) Ozone layer absorbs ultraviolet radiation from the sun and prevents it from reaching the earth and causing damage to life.

30. (a) The waves is propagating along negative y-direction of its direction is $-\hat{j}$.

(b) Comparing the given equation with the standard equation.

$$\vec{E} = E_0 \cos\left[2\pi\left(\frac{y}{\lambda} + \nu t\right)\right]$$

We get, $\frac{2\pi}{\lambda} = 1.8$

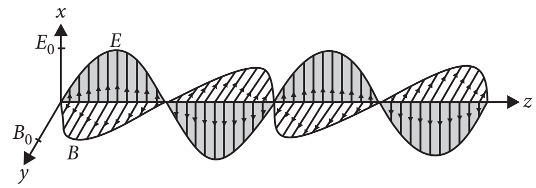
$\therefore$ Wavelength, $\lambda = \frac{2\pi}{1.8} \times \frac{2 \times 3.14}{1.8} = 3.5\,\text{m}.$

(c) Also, $2\pi\nu = 5.4 \times 10^6$

$\therefore$ $\nu = \frac{5.4 \times 10^6}{2\pi} = \frac{5.4 \times 10^8}{2 \times 3.14} = 85.9 \times 10^6$ Hz.

$\simeq 86$ MHz

31. (a) (i) The *e.m.* wave propagates along *z*-axis.



(ii) The speed of em-waves in vacuum determined by the electric (E_0) and magnetic fields (B_0) is, $c = \frac{E_0}{B_0}$

(b) Electromagnetic waves or photons transport energy and momentum. When an electromagnetic wave interacts with a small particle, it can exchange energy and momentum with the particle. The force exerted on the particle is equal to the momentum transferred per unit time. Optical tweezers use this force to provide a non-invasive technique for manipulating microscopic-sized particles with light.

32. (a) Consider a plane perpendicular to the direction of propagation of the wave. An electric charge, on the plane will be set in motion by the electric and magnetic fields of *e.m.* wave, incident on this plane. This illustrates that *e.m.* waves carry energy and momentum.

(b) Microwaves are produced by special vacuum tube like the klystron, magnetron and Gunn diode.

The frequency of microwaves is selected to match the resonant frequency of water molecules, so that energy is transformed efficiently to the kinetic energy of the molecules.

(c) Uses of infra-red waves :

(i) They are used in night vision devices during warfare. This is because they can pass through haze, fog and mist.

(ii) Infra-red waves are used in remote switches of household electrical appliances.

33. In microwave oven, the frequency of the microwaves is selected to match the resonant frequency of water molecules so that energy from the waves get transferred efficiently to the kinetic energy of the molecules. This kinetic energy raises the temperature of any food containing water.

Microwaves are short wavelength radio waves, with frequency of order of GHz. Due to short wavelength, they have high penetrating power with respect to atmosphere and less diffraction in the atmospheric layers. So these waves are suitable for the radar systems used in aircraft navigation.

33. (a) Intensity equals power per unit area carried by the wave.

$\Rightarrow$ Power per unit area $= \frac{P}{\pi r^2}$

$$= \frac{4\,\text{W}}{3.14 \times (0.2 \times 10^{-3}\,\text{m})^2}$$

$= 32 \times 10^6$ W/m^2

(b) Intensity = $\frac{E_0^2}{2\mu_0 c}$ $\Rightarrow$ $E_{\max} = E_0 = \sqrt{(2\mu_0 c)(I)}$

$= \sqrt{(8\pi \times 10^{-7})(3 \times 10^8)(32 \times 10^6)}$ SI units

$= 1.6 \times 10^5$ V/m

(c) $B_{\max} = B_0 = \frac{E_0}{c} = \frac{1.6 \times 10^5 \text{ V/m}}{3 \times 10^8 \text{m/s}} = 5.3 \times 10^{-4}$ T

(d) $\Delta P = \frac{2U}{c}$ where DP is the momentum delivered on the sphere.

$F = \frac{\Delta P}{\Delta t} = 2\left(\frac{U}{\Delta t}\right)\cdot\frac{1}{c}$

Now, $\frac{U}{\Delta t} = I.A = I(\pi r^2) \Rightarrow F = \frac{2 \cdot I \cdot \pi r^2}{c}$

Now the force F must support the sphere mass mg.

$\Rightarrow$ m = $\frac{2I\pi r^2}{gc}$

$$= \frac{2\left(3.2 \times 10^7 \frac{\text{W}}{\text{m}^2}\right)(3.14 \times 1 \times 10^{-10} \text{m}^2)}{(9.8 \text{ m/s}^2)(3 \quad 10^8 \text{ m/s})}$$

$= 6.8 \times 10^{-12}$ kg.

35. (a) Energy density of electric field E is

$u_E = \frac{1}{2}\varepsilon_0 E^2$

Energy density due to magnetic field B is,

$u_B = \frac{1}{2}\frac{B^2}{\mu_0}$

Total energy density of wave,

$= \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\frac{B^2}{\mu_0}$

Now $(u_E)_{av} = \frac{1}{T}\int_0^T u_\varepsilon dt = \frac{1}{T}\int_0^T \frac{1}{2}\varepsilon_0 E^2$

$= \frac{\varepsilon_0}{2T}\int_0^T E_0^2 \sin^2(kx - \omega t)dt$

$= \frac{\varepsilon_0}{2T}\left(E_0^2 \times \frac{T}{2}\right) = \frac{1}{4}\varepsilon_0 E_0^2$

$$\left(\int_0^T \sin^2(kx - \omega t)dt = T/2\right)$$

Similarly, $(u_B)_{av} = \frac{1}{4}\frac{B_0^2}{\mu_0}$

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

(b) $E = c B_0$ and $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$

$\therefore \quad \frac{1}{4}\frac{B_0^2}{\mu_0} = \frac{1}{4}\frac{E_0^2/c^2}{\mu_0} = \frac{E_0^2}{4\mu_0} \times \mu_0\ \varepsilon_0 = \frac{1}{4}\varepsilon_0\ E_0^2$

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

$= \frac{1}{2}\varepsilon_0 E_0^2 = \frac{1}{2}\frac{B_0^2}{\mu_0}$

Time averaged intensity

$I_{av} = u_{av} c = \frac{1}{2} c\, \varepsilon_0\ E_0^2$

☺☺☺