CHAPTER 17

Electromagnetic Waves

Chapter Highlights

Electromagnetic waves and their characteristics. Transverse nature of electromagnetic waves. Electromagnetic spectrum (radio waves, microwaves, infrared, visible, ultraviolet, *x*-rays, gamma rays). Applications of e.m. waves.

ELECTROMAGNETIC WAVE

James Clerk Maxwell, the great British physicist in 1865, predicted that a time varying electric field produces a magnetic field just as a time varying magnetic field produces an electric field. From this generalisation, he introduced the concept of displacement current, a new source of magnetic field. This provided an important link between the electric and the magnetic field. He summarised the known laws of electricity and magnetism, namely Coulomb's (or Gauss's law), Biot-Savart's (or Ampere's) law and Faraday's law and electromagnetic induction in a set of equations known as Maxwell's equations.

Maxwell's equations show that when either an electric field ($\vec{E}$) or a magnetic field ($\vec{B}$) vary with time, a field of the other kind i.e. ($\vec{B}$ for $\vec{E}$ and $\vec{E}$ for $\vec{B}$) is induced in the surrounding regions of space. Thus the electric and the magnetic fields become independent. The time varying electric and magnetic fields can sustain each other and form electromagnetic waves. He predicted that such waves propagate through free space with the speed of light. Maxwell's predictions on electromagnetic waves were experimentally confirmed by German scientist. Hertz in 1887, who first demonstrated and detected em waves.

Electromagnetic waves are produced by accelerating electric charges. Visible light, X-rays, γ-rays, microwaves and radiowaves etc. are some examples of electromagnetic waves which differ from one another in frequency and wavelength.

Displacement Current

It is the current which exists in the region in which the electric field and hence the electric flux changes with time.

It is given by

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

Where $\frac{d\phi_E}{dt}$ is the rate of change of electric flux between the plates of the capacitor.

Therefore the Ampere's circuital law as modified by Maxwell, may be expressed as

$$\int \vec{B}\cdot\vec{dl} = \mu_0\left(I_C + \varepsilon_0 \frac{d\phi_E}{dt}\right)$$

Maxwell's Equations

Maxwell's equations relate the electric and magnetic field to their respective sources which are electric charges, currents and changing fields. They form the basis of all electrical and magnetic phenomena and unify electricity and magnetism into a single discipline called electromagnetism. Their role in electromagnetism in analogous to that of Newton's laws in classical machines.

Maxwell showed that electromagnetic waves were the natural consequence of these equations. Maxwell's equations in free space are stated as below

1. $\oint \vec{E}\cdot\vec{ds} = \frac{Q}{\varepsilon_0}$ (1)

2. $\oint \vec{B}\cdot\vec{ds} = 0$ (2)

3. $\oint \vec{E}\cdot\vec{dl} = \frac{d\phi_B}{dt} = -\frac{d}{dt}\oint \vec{B}\cdot\vec{ds}$ (3)

4. $\oint \vec{B}\cdot\vec{dl} = \mu_0\left(I + \varepsilon_0 \frac{d\phi_E}{dt}\right)$ (4)

(a) Maxwell's first equation i.e. relation (1) is Gauss's law in electrostatics. It relates the electric field (E) to its source i.e. the charge Q.

(b) The second equation i.e. relation (2) is Gauss's law in magnetism. It shows that isolated magnetic monopoles do not exist.
(c) The third equation i.e. relation (3) is Faraday's law in electromagnetism. It signifies that a time varying magnetic field produces an electric field.
(d) The fourth equation i.e. relation (4) is the Modified Ampere's circuital law. It describes the relationship between the magnetic fields, electric fields and electric currents. It also signifies that a time varying electric field produces a magnetic field.

Characteristics of Electromagnetic Waves

1. Electromagnetic waves consist of time varying electric and magnetic fields such that the two fields are perpendicular to each other as well as the direction of propagation of electromagnetic waves.
2. Electromagnetic waves are produced by accelerating or oscillating charge.
3. Electromagnetic waves do not required a material medium for their propagation.
4. They travel in free space with a velocity $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$, which is equal to the velocity of light ($c = 3 \times 10^8$ m/s).
5. They are transverse in nature.
6. The electric and magnetic field i.e. $\vec{E}$ and $\vec{B}$ oscillate sinusoidally in the same phase and the ratio of their amplitudes in free space at any time instant is given by $\frac{E}{B} = c\ (3 \times 10^8 \text{m/s})$.
7. They carry energy and momentum and hence exert pressure (called radiation pressure) on the surface on which they are incident.
8. Electromagnetic waves obey the principle of superposition and exhibit the wave properties of reflection, refraction, interference, diffraction and polarization.
9. The optical effects of electromagnetic waves are due to its electric vector ($\vec{E}$). Hence $\vec{E}$ is also called the light vector.
10. The nature of electromagnetic waves depends upon their frequency.
11. The velocity (c), wavelength (λ) and the frequency (ν) for electromagnetic waves are related by the formula $c = \nu\lambda$).

Eletromagnetic Spectrum

Electromagnetic spectrum is the orderly arrangement of electromagnetic waves according to their frequency or wavelength.

Details of the electromagnetic spectrum are given in the table shown below.

S. No	Name	Wave length range (m)	Frequency range (Hz)	Source
1	γ-rays	6×10^{-15} to 1×10^{-10}	5×10^{22} to 3×10^{18}	Certain nuclear reactions such as radioactivity, Nuclear Fission and Fusion
2	X-rays	3×10^{-12} to 3×10^{-8}	10^{20} to 10^{16}	Sudden retardation of High speed electrons
3	Ultra violet rays	6×10^{-10} to 4×10^{-7}	5×10^{17} to 8×10^{14}	Excitation of atoms and vacuum spark and sun
4	Visible light optical	4×10^{-7} to 8×10^{-7}	8×10^{14} to 4×10^{14}	Excitation of atoms spark and arc flame.
5	Infra-Red	8×10^{-7} to 3×10^{-5}	4×10^{14} to 1×10^{13}	Excitation of atoms spark and molecules
6	Heat radiation	1×10^{-5} to 1×10^{-1}	3×10^{13} to 3×10^{9}	Hot bodies
7	Micro-waves	10^{-3} to 0.3	3×10^{11} to 1×10^{9}	Oscillating current in special vacuum tubes
8	Radio-waves	1×10^{-1} to 10^{4}	3×10^{9} to 10^{4}	Oscillating circuits
9	Long-wave	5×10^{6} to 10^{6}	60 to 50	Weak radiations from AC circuits

Uses of Electromagnetic Spectrum

The different regions of the total electromagnetic spectrum have been put on the following uses

1. Radiowaves are used in radar and radio broadcasting.
2. Microwaves are used in long distance wireless communications via satellites.
3. Infrared, visible and ultraviolet radiations are used to know the structure of molecules
4. Diffraction of X-rays by crystals gives the details of the structure of crystals.
5. The bones are opaque to X-rays but flesh is transparent. X-ray pictures of a human body are used in medical diagnosis of fractures and cracks of bones.
6. The γ-rays are used in the study of the structure of the nuclei of atoms.

Propagation of Electromagnetic Wave in Atmosphere

The atmosphere is transparent to visible radiation. The other components (such as infrared and ultraviolet) of the solar radiation are absorbed in different layers. The infrared radiations are called heat or thermal radiations. They produce heat when they are absorbed by a body. Now most infrared radiation from the sun is absorbed by the atmosphere. Whatever little radiation the earth receives heats the earth. Consequently the earth itself emits radiation, and this radiation is mostly in the infrared region (because the earth is much cooler than the sun; hence from Planck's law, it can emit only long–wavelength radiation such as infrared). The infrared radiation emitted from the earth cannot cross the lower atmospheric layers which reflect it back. The clouds also prevent the radiation from escaping and thus act as blankets of the earth. The lower atmosphere, therefore, becomes richer in infrared radiation and all objects on earth absorb it getting heated in the process. This phenomenon is called the Green house effect.

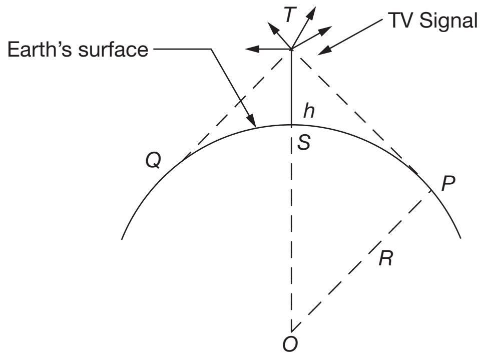
The components of the solar radiation whose wavelength is shorter than the violet (such as ultraviolet and X-ray) are dangerous; they damage the living cells. Fortunately, the ozone layer effectively absorbs these harmful components and we are protected from them.

Radiowaves and microwaves (i.e. waves whose wavelength is longer than about 1 mm) are relevant as far as transmission and communication are concerned. The earliest experiments of Hertz and Marconi on radio communication used waves of wavelengths 10 cm or more. The lower atmosphere is transparent to waves of these wavelengths but the upper atmospheric layer called the ionosphere reflects them back to earth. This property is, therefore, made use in radio communication.

A radio signal emitted from a certain location on earth can be received at another location in two possible ways. The wave can travel directly along the earth from one point to another –this is called the ground wave-or it could be directed towards the sky and reflected from the ionosphere towards a desired location on earth – this is called the sky wave.

The communication by ground wave is possible with waves of wavelengths longer than about 200 m because the lower wavelength waves are heavily damped by interaction with matter. Below this wavelength, communication through the sky wave is the only method. In common day language the two regions are referred to as the medium wave band and the short wave band.

Communication via the sky wave is not possible if the frequency of the wave is higher than about 40 MHz because the ionosphere bends these waves and does not reflect them. Therefore, television signals (whose frequencies are in the range 100-200 MHz) cannot be transmitted via the sky wave, only ground wave transmission is possible. The receiver antenna is placed directly in the path of the TV signal. The range of a TV signal can be easily computed as shown in the following.



Suppose a TV transmitter is stationed on top of a tower at a height h above the ground shown in the figure. Because of the curvature of the earth, the TV signal cannot be received beyond places marked P and Q in the figure. The distance PS and QS up to which signals can be received can be easily calculated in terms of height h and the radius R of the earth. In the right angled triangle OTP, we have

$$(OT)^2 = (OP)^2 + (TP)^2$$

Where $OT = R + h$, $OP = R$ and $TP = SP = d$ (say). We then have

$$(R+h)^2 = R^2 + d^2$$

or $$d^2 = h^2 + 2hR = 2hR\left(1 + \frac{h}{2R}\right)$$

Since $h << R$, we have $d = \sqrt{2hR}$

If the TV transmitter is at a height $h = 50$ m, the value of d works out to 80 km (radius of earth = 6.4×10^6m). The actual range is, in fact, less than 80 km due to heavy attenuation (damping) of the signals unless the transmitter is very powerful, i.e. the signals have a large amplitude (E_0) and therefore a large energy.

Electromagnetic waves of frequencies higher than TV signals are called microwaves. Their wavelength is of the order of few millimetres. We learnt in the previous chapter that such short wavelength waves are not diffracted (i.e. bent) by obstacles of normal dimensions; they travel in straight lines. Therefore, a beam of microwaves can be sent in a particular direction. A radar is a device that does this. It sends a beam of microwaves towards a distant object and receives the signal reflected back from it. Since the speed of the electromagnetic waves is $c = 3 \times 10^8$ ms^{-1}, from the measurement of the time interval between the sending and receiving of the signals, one can compute the distance of the object.

With the advent of artificial satellites, microwave telecommunications have undergone a revolution. It is now possible to transmit signals from one location on earth to almost any other location. Signals are sent from a microwave transmitter toward an artificial earth satellite which sends them back to earth. Since the satellite is at a great height (h ~ 36,000 km) above the earth, the range d becomes very large. The satellite moves in an orbit and the earth spins about its own axis. If such a satellite is to be used to transmit signals to a definite region, its orbit must be such that, relative to the earth's surface, it must appear stationary. For a satellite to appear fixed at a place above a certain place on the earth, it must co-rotate with the earth so that its orbital period round the earth is exactly equal to the rotational period of the earth about its axis of rotation. Such a satellite is called a geostationary or synchronous satellite. It is easy to calculate what height it should have to be synchronous. It turns out that, for a satellite to appear stationary, it must be placed in orbit round the earth at a height of about 36,000 km from the earth's surface. This is often called the parking orbit of the satellite. Relay satellites are placed in parking orbits to transmit TV programmes from one part of the world to another.

EXERCISES

Single Option Correct Type

1. If E and B are the electric and magnetic field vectors of electromagnetic waves then the direction of propagation of electromagnetic wave is along the direction of

(A) $\vec{E}$ (B) $\vec{B}$
(C) $\vec{E}\times\vec{B}$ (D) None of these

2. The charge on a parallel plate capacitor is varying as $q = q_0 \sin 2\pi\cdot nt$ The plates are very large and close together. Neglecting the edge effects, the displacement current through the capacitor is

(A) $\frac{q}{\varepsilon_0 A}$ (B) $\frac{q_0}{\varepsilon_0}\sin 2\pi nt$
(C) $2\pi n q_0 \cos \pi n t$ (D) $\frac{2\pi n q_0}{\varepsilon_0}\cos 2\pi nt$

3. The value of magnetic field between plates of capacitor, at distance of 1m from centre where electric field varies by 10^{10} V/m/s will be

(A) 5.56 T (B) 5.56 μT
(C) 5.56 mT (D) 55.6 nT

4. The electromagnetic waves do not transport

(A) Energy (B) Charge
(C) Momentum (D) Information

5. A capacitor is connected in an electric circuit. When key is pressed, the current in the circuit is

(A) Zero
(B) Maximum
(C) Any transient value
(D) Depends on capacitor used

6. Displacement current is continuous

(A) when electric field is changing in the circuit.
(B) when magnetic field is changing in the circuit.
(C) in both types of fields.
(D) through wires and resistance only.

7. Instantaneous displacement current 1 A in the space between the parallel plates of 1 μF capacitor can be established by changing the potential difference at the rate of

(A) 0.1 V/s (B) 1 V/s
(C) 10^6 V/s (D) 10^{-6} V/s

8. The magnetic field between the plates of a capacitor when $r > R$ is given by

(A) $\frac{\mu_0 I_D r}{2\pi R^2}$ (B) $\frac{\mu_0 I_D}{2\pi R}$
(C) $\frac{\mu_0 I_D}{2\pi r}$ (D) kwU

9. The magnetic field between the plates of a capacitor is given by $B = \frac{\mu_0 Ir}{2\pi R^2}$

(A) $r \ge R$ (B) $r \le R$
(C) $r < R$ (D) $r = R$

10. The conduction current is the same as displacement current when the source is

(A) AC only
(B) DC only
(C) Both AC and DC
(D) Neither for AC nor for DC

11. The wave function (in S.I. units) for an electromagnetic wave is given as

$$\Psi(x, t) = 10^3 \sin\pi(3\times10^6 x - 9 - 10^{14} t)$$

The speed of the wave as

(A) 9×10^{14} m/s (B) 3×10^8 m/s
(C) 3×10^{16} m/s (D) 3×10^7 m/s

12. In the above problem, wavelength of the wave is
(A) 666 nm (B) 666 Å
(C) 666 μm (D) 6.66 nm

13. The Maxwell's four equations are written as

(i) $\oint \vec{E} \cdot \vec{ds} = \dfrac{q_0}{\varepsilon_0}$

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

(iii) $\oint \vec{E} \cdot \vec{dl} = \dfrac{d}{dt} \oint \vec{B} \cdot \vec{ds}$

(iv) $\oint \vec{B} \cdot \vec{ds} = \mu_0 \varepsilon_0 \dfrac{d}{dt} \oint \vec{E} \cdot \vec{ds}$

The equations which have sources of $\vec{E}$ and $\vec{B}$
(A) (i), (ii) and (iii) (B) (i) and (ii)
(C) (i) and (iii) (D) (i) and (iv)

14. Out of the above four equations which do not contain source field are
(A) (i) and (ii) (B) (ii) Only
(C) All of four (D) (iii) Only

15. Out of four Maxwell's equations above, which one shows non-existence of monopoles?
(A) (i) and (iv) (B) (ii) Only
(C) (iii) Only (D) (i) Only

16. Which of the above Maxwell's equations shows that electric field lines do not form closed loops?
(A) (i) only (B) (ii) only
(C) (iii) only (D) (iv) only

17. In an electromagnetic wave the average energy density is associated with
(A) electric field only.
(B) magnetic field only.
(C) equally with electric and magnetic fields.
(D) average energy density is zero.

18. In an electromagnetic wave the average energy density associated with magnetic field will be
(A) $\dfrac{1}{2}LI^2$ (B) $\dfrac{B^2}{2\mu_0}$
(C) $\dfrac{1}{2}\mu_0 B^2$ (D) $\dfrac{1}{2}\dfrac{q}{B^2}$

19. In the above problem, the energy density associated with the electric field will be
(A) $\dfrac{1}{2}CV^2$ (B) $\dfrac{1}{2}\dfrac{q^2}{C}$
(C) $\dfrac{1}{2}\dfrac{\varepsilon^2}{E}$ (D) $\dfrac{1}{2}\varepsilon_0 E^2$

20. If there were no atmosphere, the average temperature on earth surface would be
(A) Lower (B) Higher
(C) Same (D) 0°C

21. In which part of earth's atmosphere is the ozone layer present?
(A) Troposphere (B) Stratosphere
(C) Ionosphere (D) Mesosphere

22. Kenneley's Heaviside layer lies between
(A) 50 km to 80 km
(B) 80 km to 400 km
(C) beyond 110 km
(D) beyond 250 km

23. The ozone layer in earth's atmosphere is crucial for human survival because it
(A) has ions.
(B) reflects radio signals.
(C) reflects ultraviolet ray.
(D) reflects infra red rays.

24. The frequency from 3×10^9 Hz to 3×10^{10} Hz
(A) High frequency band
(B) Super high frequency band
(C) Ultra high frequency band
(D) High frequency band

25. The frequency from 3 to MHz is known as
(A) Audio band
(B) Medium frequency band
(C) Very high frequency band
(D) High frequency band

26. The AM range of radio waves have frequency
(A) Less than 30 MHz
(B) More than 30 MHz
(C) Less than 20000 Hz
(D) More than 20000 Hz

27. The displacement current flows in the dielectric of a capacitor
(A) becomes zero.
(B) has assumed a constant value.
(C) is increasing with time.
(D) is decreasing with time.

28. Select wrong statement from the following Electromagnetic waves
(A) are transverse.
(B) travel with same speed in all media.
(C) travel with the speed of light.
(D) are produced by acceleration charge.

29. The waves related to telecommunication are
(A) Infra red (B) Visible light
(C) Microwaves (D) Ultraviolet rays

30. Electromagnetic waves do not transport
(A) Energy (B) Charge
(C) Momentum (D) Information

31. The nature of electromagnetic wave is
(A) Longitudinal
(B) Longitudinal stationary
(C) Transverse
(D) Transverse stationary

32. Greenhouse effect keeps the earth surface
(A) Cold at night (B) Dusty and cold
(C) Warm at night (D) Moist

33. A parallel plate capacitor consists of two circular plates each of radius 12 cm and separated by 5.0 mm. The capacitor is being charged by an external source. The charging is being charged and is equal to 0.15 A. The rate of change of potential difference between the plates will be
(A) 8.173×10^7 V/s (B) 7.817×10^8 V/s
(C) 1.873×10^9 V/s (D) 3.781×10^{10} V/s

34. In the above problem, the displacement current is
(A) 15 A (B) 1.5 A
(C) 0.15 A (D) 0.015 A

35. The wave emitted by any atom or molecule must have some finite total length which is known as the coherence length. For sodium light, this length is 2.4 cm. The number of oscillations in this length will be
(A) 4.068×10^5 (B) 4.068×10^6
(C) 4.068×10^7 (D) 4.068×10^8

36. In the above problem, the coherence time will be
(A) 8×10^{-8}s (B) 8×10^{-9}s
(C) 8×10^{-10}s (D) 8×10^{-11}s

37. A parallel plate capacitor made to circular plates each of radius R = 6 cm has capacitance C = 100 pF. The capacitance is connected to a 230 V AC supply with an angular frequency of 300 rad/s. The rms value of conduction current will be
(A) 5.7 μA (B) 6.3 μA
(C) 9.6 μA (D) 6.9 μA

38. In the above problem, the displacement current will be
(A) 6.9 μA (B) 9.6 μA
(C) 6.3 μA (D) 5.7 μA

39. In Q. 37, the value of B at a point 3 cm from the axis between the plates will be
(A) 1.63×10^{-8} T (B) 1.63×10^{-9} T
(C) 1.63×10^{-10} T (D) 1.63×10^{-11} T

40. A plane electromagnetic wave of frequency 40 MHz travels in free space in the x-direction. At some point and at some instant, the electric field $\vec{E}$ has its maximum value of 750 N/C in y-direction. The wavelength of the wave is
(A) 3.5 m (B) 5.5 m
(C) 7.5 m (D) 9.5 m

41. In the above problem, the period of the wave will be
(A) 2.5 μs (B) 0.25 μs
(C) 0.025 μs (D) None of these

42. In Q. 40, the magnitude and direction of magnetic field will be
(A) 2.5 μT in x-direction
(B) 2.5 μT in y-direction
(C) 2.5 μT z-direction
(D) None of these

43. In Q. 40, the angular frequency of e.m.f. wave will be (in rad/s)
(A) $8\pi \times 10^7$ (B) $4\pi \times 10^6$
(C) $4\pi \times 10^5$ (D) $8\pi \times 10^4$

44. In Q. 40, the propagation constant of the wave will be
(A) 8.38m^{-1} (B) 0.838m^{-1}
(C) 4.19m^{-1} (D) 0.419m^{-1}

45. The sun delivers 10^3 W/m^2 of electromagnetic flux to the earth's surface. The total power that is incident on a roof of dimensions 8m $\times$ 20m, will be
(A) 6.4×10^3 W (B) 3.4×10^4 W
(C) 1.6×10^5 W (D) None of these

46. In the above problem, the radiation force on the
(A) 3.33×10^{-5}N (B) 5.33×10^{-4} N
(C) 7.33×10^{-3} N (D) None of these

47. In Q. 45, the solar energy incident on the roof in 1 hour will be
(A) 5.76×10^8J (B) 5.76×10^7J
(C) 5.76×10^6J (D) 5.76×10^5J

48. The sun radiates electromagnetic energy at the rate of 3.9×10^{26} W. Its radius is 6.96×10^8 m. The intensity of sun light at the solar surface will be
(A) 1.4×10^4 (B) 2.8×10^5
(C) 4.2×10^6 (D) 5.6×10^7

49. In the above problem, if the distance from the sun to the earth is 1.5×10^{11} m, then the intensity of sunlight on earth's surface will be (in W/m^2)

(A) 1.38×10^3
(B) 2.76×10^4
(C) 5.52×10^5
(D) 3.74×10^3

50. A laser beam can be focussed on an area equal to the square of its wavelength. A He-Ne laser radiates energy at the rate of 1 nW and its wavelength is 632.8 nm. The intensity of focussed beam will be

(A) 1.5×10^{13} W/m^2 (B) 2.5×10^9 W/m^2
(C) 3.5×10^{17} W/m^2 (D) None of these

51. A flood light is covered with a filter that transmits red light. The electric field of the emerging beam is represented by a sinusoidal plane wave

$$E_x = 36 \sin (1.20 \times 10^7 z - 3.6 \times 10^{15} t) \text{ V/m}$$

The average intensity of the beam will be

(A) 0.86 W/m^2 (B) 1.72 W/m^2
(C) 3.44 W/m^2 (D) 6.88 W/m^2

52. An electric field of 300 V/m is confined to a circular area 10 cm in diameter. If the field is increasing at the rate of 20 V/m-s, the magnitude of magnetic field at a point 15 cm from the centre of the circle will be

(A) 1.85×10^{-15} T (B) 1.85×10^{-16} T
(C) 1.85×10^{-17} T (D) 1.85×10^{-18} T

53. A lamp emits monochromatic green light uniformly in all directions. The lamp is 3% efficient in converting electrical power to electromagnetic waves and consumes 100 W of power. The amplitude of the electric field associated with the electromagnetic radiation at a distance of 10 m from the lamp will be

(A) 1.34 V/m (B) 2.68 V/m
(C) 5.36 V/m (D) 9.37 V/m

54. A plane electromagnetic wave of wave intensity 6 W/m^2 strikes a small mirror of area 40 cm^2, held perpendicular to the approaching wave. The momentum transferred by the wave to the mirror each second will be

(A) 6.4×10^{-7} kg–m/s
(B) 4.8×10^{-8} kg–m/s
(C) 3.2×10^{-9} kg–m/s
(D) 1.6×10^{-10} kg–m/s

55. In the above problem, the radiation force on the mirror will be

(A) 6.4×10^{-7} N (B) 4.8×10^{-8} N
(C) 3.2×10^{-9} N (D) 1.6×10^{-10} N

56. In the above problem, the wavelength of the wave will be

(A) 1.5 m (B) 66.6 m
(C) 1.5 cm (D) 66.6 cm

57. In Q. 5, the energy density at a distance 3.5 m from the source will be (in joule/m^3)

(A) 1.73×10^{-5} (B) 1.73×10^{-6}
(C) 1.73×10^{-7} (D) 1.73×10^{-8}

58. A 100 pF capacitor is connected to a 230 V, 50 Hz AC source. The rms value of conduction current will be

(A) 7.2×10^{-6} A (B) 3.6×10^{-5} A
(C) 1.8×10^{-4} A (D) 0.9×10^{-3} A

59. What should be the height of transmitting antenna if the TV telecast is to cover a radius of 128 km?

(A) 1560 m (B) 1280 m
(C) 1050 m (D) 79 m

60. The area to be covered for TV telecast is doubled, then the height of transmitting antenna (TV tower) will have to be

(A) Doubled (B) Halved
(C) Quardupled (D) Kept unchanged

Previous Years' Questions

61. Infrared radiation is detected by **[2002]**

(A) Spectrometer (B) Pyrometer
(C) Nanometer (D) Photometer

62. Electromagnetic waves are transverse in nature is evident by **[2002]**

(A) Polarization (B) Interference
(C) Reflection (D) Diffraction

63. Which of the following are not electromagnetic waves? **[2002]**

(A) Cosmic rays (B) Gamma rays
(C) β-rays (D) x-rays

64. Consider telecommunication through optical fibres. Which of the following statements is not true? **[2003]**

(A) Optical fibres can be of graded refractive index.
(B) Optical fibres are subject to electromagnetic interference from outside.
(C) Optical fibres have extremely low transmission loss.
(D) Optical fibres may have homogeneous core with a suitable cladding.

65. An electromagnetic wave of frequency $v = 3.0\,\text{MHz}$ passes from vacuum into a dielectric medium with permittivity $\varepsilon = 4.0$. Then **[2004]**

(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 remain unchanged.

66. The rms value of the electric field of the light coming from the sun is 720 N/C. The average total energy density of the electromagnetic wave is **[2006]**

(A) 3.3×10^{-3} J/m^3 (B) 4.58×10^{-6} J/m^3
(C) 6.37×10^{-9} J/m^3 (D) 81.35×10^{-12} J/m^3

67. This question has Statement 1 and Statement 2. Of the four choices given after the statements, choose the one that best describes the two statements. **[2011]**

Statement-1: Sky wave signals are used for long distance radio communication. These signals are in general, less stable than ground wave signals are in general, less stable than ground wave signals.
Statement-2: The state of ionosphere varies from hour to hour, day to day and season to season.

(A) Statement-1 is true, Statement-2 is false.
(B) Statement-1 is true, Statement-2 is true, Statement-2 is the correct explanation of Statement-1.
(C) Statement 1 is true, Statement 2 is true, Statement 2 is not the correct explanation of Statement 1.
(D) Statement 1 is false, Statement 2 is true.

68. An electromagnetic wave in vacuum has the electric and magnetic fields $\vec{E}$ and $\vec{B}$, which are always perpendicular to each other. The direction of polarizations is given by $\vec{X}$ and that of wave propagation by $\vec{k}$ Then **[2012]**

(A) $\vec{X} \parallel \vec{E}$ and $\vec{k} \parallel \vec{E}\times\vec{B}$
(B) $\vec{X} \parallel \vec{B}$ and $\vec{K} \parallel \vec{E}\times\vec{B}$
(C) $\vec{X} \parallel \vec{E}$ and $\vec{k} \parallel \vec{B}\times\vec{E}$
(D) $\vec{X} \parallel \vec{B}$ and $\vec{k} \parallel \vec{B}\times\vec{E}$

69. A radar has power of 1 kW and is operating at a frequency of 10 GHz. It is located on a mountain top of height 500 m. The maximum distance up to which it can detect object located on the surface of the earth (Radius of earth $= 6.4\times10^6$ m) is **[2012]**

(A) 16 km (B) 40 km
(C) 64 km (D) 80 km

70. The magnetic field in a travelling electromagnetic wave has a peak value of 20 nT. The peak value of electric field strength is **[2013]**

(A) 12 V/m (B) 3 V/m
(C) 6 V/m (D) 9 V/m

71. During the propagation of electromagnetic waves in a medium **[2014]**

(A) Both electric and magnetic energy densities are zero.
(B) Electric energy density is half of the magnetic energy density.
(C) Electric energy density is half of the magnetic energy density.
(D) Electric energy density is equal to the magnetic energy density.

72. Match List-I (Electromagnetic wave type) with List-II (Its association/application)and select the correct option from the choices given below the lists. **[2014]**

List-I	List-II
(P) Infrared wave	(i) To treat muscular strain
(Q) Radio waves	(ii) For broadcasting
(R) X-rays	(iii) To detect fracture of bones
(S) Ultraviolet rays	(iv) Absorbed by the ozone layer of the atmosphere

	P	Q	R	S
(A)	i	ii	iii	iv
(B)	iv	iii	ii	i
(C)	i	ii	iv	iii
(D)	iii	ii	i	iv

73. A red LED emits light at 0.1 watt uniformly around it. The amplitude of the electric field of the light at a distance of 1 m from the diode is **[2015]**

(A) 2.45 V/m (B) 5.48 V/m
(C) 7.75 V/m (D) 1.73 V/m

74. Arrange the following electromagnetic radiations per quantum in the order of increasing energy: **[2016]**

(i) Blue light (ii) Yellow light
(iii) X-ray (iv) Radio wave

(A) (i), (ii), (iv) and (iii)
(B) (iii), (i), (ii) and (iv)
(C) (ii), (i), (iv) and (iii)
(D) (iv), (ii), (i) and (iii)

ANSWER KEYS

Single Option Correct Type

1. (C)	**2.** (C)	**3.** (D)	**4.** (B)	**5.** (B)	**6.** (A)	**7.** (C)	**8.** (C)	**9.** (C)	**10.** (B)
11. (B)	**12.** (A)	**13.** (D)	**14.** (B)	**15.** (B)	**16.** (A)	**17.** (C)	**18.** (B)	**19.** (D)	**20.** (A)
21. (B)	**22.** (C)	**23.** (C)	**24.** (B)	**25.** (B)	**26.** (A)	**27.** (C)	**28.** (B)	**29.** (C)	**30.** (A)
31. (C)	**32.** (C)	**33.** (C)	**34.** (C)	**35.** (B)	**36.** (D)	**37.** (D)	**38.** (A)	**39.** (D)	**40.** (C)
41. (C)	**42.** (C)	**43.** (A)	**44.** (B)	**45.** (C)	**46.** (B)	**47.** (A)	**48.** (D)	**49.** (A)	**50.** (B)
51. (B)	**52.** (D)	**53.** (A)	**54.** (D)	**55.** (D)	**56.** (C)	**57.** (D)	**58.** (A)	**59.** (B)	**60.** (A)

Previous Years' Questions

61. (B)	**62.** (A)	**63.** (C)	**64.** (B)	**65.** (C)	**66.** (B)	**67.** (B)	**68.** (A)	**69.** (D)	**70.** (C)
71. (D)	**72.** (A)	**73.** (A)	**74.** (D)						

HINTS AND SOLUTIONS

Single Option Correct Type

1. The correct option is (C)

2. $I_D = \frac{dq}{dt} = \frac{d}{dt} q_0 \sin 2\pi nt = 2\pi n q_0 \cos 2\pi q_0 \cos 2\pi nt$

The correct option is (C)

3. $B = \frac{\mu_0 \varepsilon_0 r}{2}\frac{dE}{dt} = \frac{1}{2\times 9\times 10^{16}}\times 10^{10} = 5.56\times 10^{-8}$ T

The correct option is (D)

4. The correct option is (B)

5. The correct option is (B)

6. The correct option is (A)

7. $I_D = \frac{dq}{dt} = C\frac{dv}{dt}$ or $\frac{dv}{dt} = \frac{I_D}{C} = \frac{1}{10^{-6}} = 10^6$ V/s

The correct option is (C)

8. According to Ampere's law, when $r > R$ $B = \frac{\mu_0 I_D}{2\pi r}$

The correct option is (C)

9. According to Ampere's law, when $r > R$ $B = \frac{\mu_0 I_{Dr}}{2\pi R^2}$

The correct option is (C)

10. The correct option is (B)

11. $c = \frac{\omega}{k} = \frac{9\times 10^{14}}{3\times 10^6} = 3\times 10^8$ m/s

The correct option is (B)

12. $\Psi(x,t) = 10^3 \sin 3\times 10^6 \pi\, (x - 3\times 10^8\, t)$

The correct option is (A)

Comparing it with

$\Psi(x,t) = a \sin \frac{2\pi}{\lambda}(x - vt)$

$\therefore \quad \frac{2\pi}{\lambda} = 3\times 10^6 \pi$

or $\quad \lambda = \frac{2\times 10^9}{3\times 10^6} = 666$ nm

13. The correct option is (D)

14. The correct option is (B)

15. The correct option is (B)

16. The correct option is (A)

17. The correct option is (C)

18. The correct option is (B)

19. The correct option is (D)

20. The green house effect would not have been possible without atmosphere. Hence temperature would be lower.

The correct option is (A)

21. The correct option is (B)

22. The correct option is (C)

23. The correct option is (C)

24. The correct option is (B)

25. The correct option is (B)

26. The correct option is (A)

27. The correct option is (C)

28. The correct option is (B)

29. The correct option is (C)

30. The correct option is (A)

31. The correct option is (C)

32. The correct option is (C)

33. $\frac{dV}{dt} = \frac{I}{C} = \frac{I_d}{\varepsilon_0 A}$

$= \frac{0.15 \times 5 \times 10^{-3}}{8.85 \times 10^{-12} \times 3.14 \times 0.0144}$

$= 1.873 \times 10^9$ V/s

The correct option is (C)

34. $I_D = I_C = 0.15$ A

The correct option is (C)

35. Number of oscillations in coherence length

$= \frac{l}{\lambda} = \frac{0.024}{5.9 \times 10^{-7}} = 4.068 \times 10^6$ Hz

The correct option is (B)

36. The coherence time t $= \frac{l}{c} = \frac{0.024}{3 \times 10^8} = 8 \times 10^{-11}$ ls

The correct option is (D)

37. $I_{rms} = \frac{E_{RMS}}{X_C} = \omega C E_{rms}$

$= 300 \times 10^{-10} \times 230 = 6.9\ \mu$A

The correct option is (D)

38. $I_D = I_C = 6.9\ \mu$A

The correct option is (A)

39. $B_0 = \frac{\mu_0 (I_D)_{peak} r}{2\pi R^2}$

$= \frac{2 \times 10^{-7} \times \sqrt{2} \times 6.9 \times 10^{-6}}{2 \times 3.14 \times 36 \times 10^{-4}}$

$= 1.63 \times 10^{-11}$ T

The correct option is (D)

40. $\lambda = \frac{C}{f} = \frac{3 \times 10^8}{4 \times 10^7} = 7.5$ m

The correct option is (C)

41. $T = \frac{1}{f} = \frac{1}{4 \times 10^7} = 0.025\ \mu$s

The correct option is (C)

42. $B_m = \frac{E_m}{C} \frac{750}{3 \times 10^8} = 2.5\ \mu$T   Z-directional

The correct option is (C)

43. $\omega = 2\pi f = 2 \times \pi \times 4 \times 10 = 8\pi \times 10^7$ rad/s.

The correct option is (A)

44. $K = \frac{2\pi}{\lambda} = \frac{2 \times 3.14}{7.5} = 0.838\ \text{m}^{-1}$

The correct option is (B)

45. Power $P = 5$ A $= 10^3 \times 8 \times 20 = 1.6 \times 10^5$ W

The correct option is (C)

46. $F = PA = F = PA = \frac{SA}{c} = \frac{1.6 \times 10^5}{3 \times 10^8} = 5.33 \times 10^{-4}$

The correct option is (B)

47. E = power × time

$= 1.6 \times 10^5 \times 3600 = 5.76 \times 10^8$ J

The correct option is (A)

48. $I_{surface} = \frac{P}{A} = \frac{3.9 \times 10^{26}}{4 \times 3.14 \times (6.96)^2 \times 10^{16}} = 5.6 \times 10^7\ \text{W/m}^2$

The correct option is (D)

49. $I_{earth} = \frac{P}{4\pi r^2} = \frac{3.9 \times 10^{26}}{4 \times 3.14 \times 2.25 \times 10^{22}} = 1.38 \times 10^3\ \text{W/m}^2$

The correct option is (A)

50. Area through which the energy of beam passes

$= (6.328 \times 10^{-7})^2 = 4 \times 10^{-13}\ \text{m}^2$

$\therefore\ I = \frac{P}{A} = \frac{10^{-3}}{4 \times 10^{-13}} = 2.5 \times 10^9\ \text{W/m}^2$

The correct option is (B)

51. $I_{av} = \frac{c\varepsilon_0 E_0^2}{2} = \frac{3 \times 10^8 \times 8.85 \times 10^{-12} \times 36^2}{2}$

$= 1.72\ \text{W/m}^2$

The correct option is (B)

52. $B = \frac{\mu_0 \varepsilon_0}{2\pi R} \left(\frac{\pi d^2}{4} \right) \frac{dE}{dt}$

$= \frac{2 \times 10^{-7} \times 8.85 \times 10^{-12} \times 3.14 \times 0.01 \times .20}{4 \times 0.15} = 1.85 \times 10^{-18}$ T

The correct option is (D)

53. $S_{av} = \frac{P}{4\pi R^2} = \frac{1}{2} \varepsilon_0 c E_0^2$

$\therefore\ E_0 \sqrt{\frac{P}{2\pi R^2 \varepsilon_0 c}}$

$= \sqrt{\frac{3}{2 \times 3.14 \times 100 \times 8.85 \times 10^{-12} \times 3 \times 10^8}}$

$= 1.34$ V/m

The correct option is (A)

54. In one second

$P = \frac{2U}{c} = \frac{2S_{av}A}{c} = \frac{2 \times 6 \times 40 \times 10^{-4}}{3 \times 10^8}$

$= 1.6 \times 10^{-10}$ kg-m/s

The correct option is (D)

55. $\therefore$ Momentum per sec is force

$\therefore\ F = 1.6 \times 10^{-10}$ Newton

The correct option is (D)

56. Wavelength of electromagnetic wave

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

The correct option is (C)

57. Energy density at 3.5 m is given by

$$u = \frac{1}{2}\varepsilon_0 E_m^2$$

$$= \frac{1}{2}\times 8.85\times10^{-12}\times(62.6)^2$$

$$= 1.73\times10^{-8}$$

The correct option is (D)

58. The rms value of conduction current

$$I = \frac{V}{Z} = \frac{V}{\frac{1}{2\pi nC}} = 2\pi nCV$$

or $I = 2\times3.14\times50\times100\times10^{-12}\times230$

$= 7.2\times10^{-6}$ A

The correct option is (A)

59. Height of transmitting antenna

$$h = \frac{d^2}{2\text{Re}} = \frac{(128\times10^3)^2}{2\times6.4\times10^6} = 1280 \text{ m}$$

The correct option is (B)

60. The area of transmission surrounding the TV tower

$A = \pi d^2 = \pi(2hRe)$

$A \propto h$

The correct option is (A)

Previous Years' Questions

61. Infrared radiation produces thermal effect and is detected by pyrometer.

The correct option is (B)

62. Polarization proves the transverse nature of electromagnetic waves

The correct option is (A)

63. β-rays are not electromagnetic waves.

The correct option is (C)

64. Optical fibres are subject to electromagnetic interference from outside.

The correct option is (B)

65. During propagation of a wave from one medium to another, frequency remains constant and wavelength changes

$$\mu = \sqrt{\frac{\varepsilon}{\varepsilon_0}} = \sqrt{4} = 2$$

Since $\mu \propto \frac{1}{\lambda}$

$\therefore$ Wavelength is halved

Hence option (C) holds good.

The correct option is (C)

66. $u = \frac{1}{2}\varepsilon_0 E_{\text{rms}}^2 + \frac{1}{2\mu_0}B_{\text{rms}}^2$

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

$$= \frac{1}{2}\varepsilon_0 E_{\text{rms}}^2 + \frac{1}{2\mu_0}E_{\text{rms}}^2\varepsilon_0\mu_0$$

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

$$= (8.85\times10^{-12})\times(720)^2$$

$$= 4.58\times10^{-6} \text{ Jm}^{-3}$$

The correct option is (B)

67. The correct option is (B)

68. The direction of polarization is parallel to electric field.

$\therefore \vec{X} \parallel \vec{E}$

The direction of wave propagation is parallel to

$\vec{E}\times\vec{B}$

$\therefore \vec{k} \parallel \vec{E}\times\vec{B}$

The correct option is (A)

69. Maximum distance on earth where object can be detected is d, then

$(h+R)^2 = d^2 + R^2$

$d^2 = h^2 + 2Rh$

$\because h << R$

$\therefore d = \sqrt{2Rh}$

$d = \sqrt{2\times6.4\times10^6\times500} = 8\times10^4 \text{ m} = 80 \text{ km}$

The correct option is (D)

70. In electromagnetic wave, the peak value of electric field (E_0) and peak value of magnetic field (B_0) are related by

$E_0 = B_0 c$

$E_0 = (20 \times 10^{-9}\ \text{T})(3 \times 10^8\ \text{ms}^{-1}) = 6\ \text{V/m}$

The correct option is (C)

71. In an em wave, energy is equally divided between the electric and the magnetic fields.

The correct option is (D)

72. Infrared waves are used to treat muscular strain. Radio waves are used for broadcasting.

x-rays are used to defect fracture of bones. Ultraviolet rays are observed by the ozone layer of the atmosphere.

The correct option is (A)

73. $\frac{1}{2}\varepsilon_0 E_0^2\, c = I$

I = intensity; P = Power (= 0.1 W); r = distance (= 1 m); c = speed of light

$$\Rightarrow \quad E_0 = \sqrt{\frac{2I}{\varepsilon_0 c}}$$

$$= \sqrt{\frac{2}{\varepsilon_0 c} \cdot \frac{P}{4\pi r^2}}$$

$$= \sqrt{\frac{2}{4\pi\varepsilon_0} \times \frac{P}{\text{c}.r^2}}$$

$$= 2.45\ \text{V/m}$$

The correct option is (A)

74. Increasing order of energy is

$E_{\text{radio}} < E_{\text{yellow}} < E_{\text{blue}} < E_{x\text{-ray}}$

The correct option is (D)