CHAPTER 8

Electromagnetic Waves

8.2 Displacement Current

1. A parallel plate capacitor of capacitance 20 μF is being charged by a voltage source whose potential is changing at the rate of 3 V/s. The conduction current through the connecting wires, and the displacement current through the plates of the capacitor, would be, respectively
(a) zero, zero
(b) zero, 60 μA
(c) 60 μA, 60 μA
(d) 60 μA, zero
(NEET 2019)

2. A 100 Ω resistance and a capacitor of 100 Ω reactance are connected in series across a 220 V source. When the capacitor is 50% charged, the peak value of the displacement current is
(a) 2.2 A
(b) 11 A
(c) 4.4 A
(d) $11\sqrt{2}$ A *(NEET-II 2016)*

8.3 Electromagnetic Waves

3. Light with an average flux of 20 W/cm^2 falls on a non-reflecting surface at normal incidence having surface area 20 cm^2. The energy received by the surface during time span of 1 minute is
(a) 10×10^3 J
(b) 12×10^3 J
(c) 24×10^3 J
(d) 48×10^3 J *(NEET 2020)*

4. The ratio of contributions made by the electric field and magnetic field components to the intensity of an electromagnetic wave is (c = speed of electromagnetic waves)
(a) $c : 1$
(b) $1 : 1$
(c) $1 : c$
(d) $1 : c^2$ *(NEET 2020)*

5. For a transparent medium relative permeability and permittivity, μ_r and ε_r are 1.0 and 1.44 respectively. The velocity of light in this medium would be
(a) 2.5×10^8 m/s
(b) 3×10^8 m/s
(c) 2.08×10^8 m/s
(d) 4.32×10^8 m/s
(Odisha NEET 2019)

6. An em wave is propagating in a medium with a velocity $\vec{v} = v\hat{i}$. The instantaneous oscillating electric field of this em wave is along $+y$ axis. Then the direction of oscillating magnetic field of the em wave will be along
(a) $-z$ direction
(b) $+z$ direction
(c) $-y$ direction
(d) $-x$ direction
(NEET 2018)

7. In an electromagnetic wave in free space the root mean square value of the electric field is $E_{rms} = 6$ V m^{-1}. The peak value of the magnetic field is
(a) 2.83×10^{-8} T
(b) 0.70×10^{-8} T
(c) 4.23×10^{-8} T
(d) 1.41×10^{-8} T
(NEET 2017)

8. Out of the following options which one can be used to produce a propagating electromagnetic wave ?
(a) A chargeless particle
(b) An accelerating charge
(c) A charge moving at constant velocity
(d) A stationary charge *(NEET-I 2016)*

9. Light with an energy flux of 25×10^4 W m^{-2} falls on a perfectly reflecting surface at normal incidence. If the surface area is 15 cm^2, the average force exerted on the surface is
(a) 1.25×10^{-6} N
(b) 2.50×10^{-6} N
(c) 1.20×10^{-6} N
(d) 3.0×10^{-6} N *(2014)*

10. An electromagnetic wave of frequency $\upsilon = 3.0$ MHz passes from vacuum into a dielectric medium with relative permittivity $\varepsilon = 4.0$. Then
(a) Wavelength is doubled and frequency becomes half.
(b) Wavelength is halved and frequency remains unchanged.
(c) Wavelength and frequency both remain unchanged.
(d) Wavelength is doubled and frequency unchanged
(Karnataka NEET 2013)

11. The electric field associated with an em wave in vacuum is given by
$[E = \hat{i}40\cos(kz - 6 \times 10^8 t)]$; where E, z and t are in volt/m, meter and seconds 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) $3\ \text{m}^{-1}$ *(2012)*

12. 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. *(Mains 2012)*

13. The electric and the magnetic field, associated with an e.m. wave, propagating along the $+z$-axis, can be represented by
(a) $\left[\vec{E} = E_0\hat{i},\ \vec{B} = B_0\hat{j}\right]$ (b) $\left[\vec{E} = E_0\hat{k},\ \vec{B} = B_0\hat{i}\right]$
(c) $\left[\vec{E} = E_0\hat{j},\ \vec{B} = B_0\hat{i}\right]$ (d) $\left[\vec{E} = E_0\hat{j},\ \vec{B} = B_0\hat{k}\right]$
(2011)

14. 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 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 *(2010)*

15. The electric field of an electromagnetic wave in free space is given by $\vec{E} = 10\cos(10^7 t + kx)\hat{j}\ \text{V/m}$, where t and x are in seconds and metres respectively. It can be inferred that
(1) the wavelength λ is 188.4 m.
(2) the wave number k is 0.33 rad/m.
(3) the wave amplitude is 10 V/m.
(4) the wave is propagating along $+x$ direction.
Which one of the following pairs of statements is correct?
(a) (3) and (4) (b) (1) and (2)
(c) (2) and (3) (d) (1) and (3)
(Mains 2010)

16. 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. *(2009)*

17. The velocity of electromagnetic radiation in a medium of permittivity ε_0 and permeability μ_0 is given by
(a) $\dfrac{1}{\sqrt{\mu_0\varepsilon_0}}$ (b) $\sqrt{\dfrac{\mu_0}{\varepsilon_0}}$
(c) $\sqrt{\dfrac{\varepsilon_0}{\mu_0}}$ (d) $\sqrt{\mu_0\varepsilon_0}$ *(2008)*

18. The electric and magnetic field of an electromagnetic wave 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. *(2007, 1994)*

19. The velocity of electromagnetic wave is parallel to
(a) $\vec{B}\times\vec{E}$ (b) $\vec{E}\times\vec{B}$ (c) $\vec{E}$ (d) $\vec{B}$ *(2002)*

20. Wavelength of light of frequency 100 Hz is
(a) 4×10^6 m (b) 3×10^6 m
(c) 2×10^6 m (d) 5×10^{-5} m *(1999)*

21. If ε_0 and μ_0 are the electric permittivity and magnetic permeability in a free space, ε and μ are the corresponding quantities in medium, the index of refraction of the medium is
(a) $\sqrt{\dfrac{\varepsilon_0\mu_0}{\varepsilon\,\mu}}$ (b) $\sqrt{\dfrac{\varepsilon\mu}{\varepsilon_0\mu_0}}$
(c) $\sqrt{\dfrac{\varepsilon_0\mu}{\varepsilon\,\mu_0}}$ (d) $\sqrt{\dfrac{\varepsilon}{\varepsilon_0}}$ *(1997)*

22. The frequency of electromagnetic wave, which best suited to observe a particle of radius 3×10^{-4} cm is of the order of
(a) 10^{15} (b) 10^{14}
(c) 10^{13} (d) 10^{12} *(1991)*

8.4 Electromagnetic Spectrum

23. The energy of the em waves is of the order of 15 keV. To which part of the spectrum does it belong?
(a) Ultraviolet rays (b) γ-rays
(c) X-rays (d) Infra-red rays *(2015)*

24. The condition under which a microwave oven heats up a food item containing water molecules most efficiently is
(a) microwaves are heat waves, so always produce heating
(b) infra-red waves produce heating in a microwave oven
(c) the frequency of the microwaves must match the resonant frequency of the water molecules
(d) the frequency of the microwaves has no relation with natural frequency of water molecules. *(NEET 2013)*

25. The decreasing order of wavelength of infrared, microwave, ultraviolet and gamma rays is
(a) microwave, infrared, ultraviolet, gamma rays
(b) gamma rays, ultraviolet, infrared, microwaves
(c) microwaves, gamma rays, infrared, ultraviolet
(d) infrared, microwave, ultraviolet, gamma rays *(2011)*

26. If λ_v, λ_x and λ_m represent the wavelengths of visible light, X-rays and microwaves respectively, then
(a) $\lambda_m > \lambda_x > \lambda_v$ (b) $\lambda_m > \lambda_v > \lambda_x$
(c) $\lambda_v > \lambda_x > \lambda_m$ (d) $\lambda_v > \lambda_m > \lambda_x$. *(2005)*

27. We consider the radiation emitted by the human body. Which one of the following statements is true?
(a) The radiation emitted is in the infrared region.
(b) The radiation is emitted only during the day.
(c) The radiation is emitted during the summers and absorbed during the winters.
(d) The radiation emitted lies in the ultraviolet region and hence is not visible. *(2003)*

28. Which of the following rays are not electromagnetic waves ?
(a) X-rays (b) γ-rays
(c) β-rays (d) heat rays *(2003)*

29. What is the cause of Green house effect?
(a) Infra-red rays
(b) Ultra violet rays
(c) X-rays
(d) Radio waves *(2002)*

30. Biological importance of ozone layer is
(a) it stops ultraviolet rays
(b) ozone layer reduces green house effect
(c) ozone layer reflects radio waves
(d) ozone layer controls O_2/H_2 ratio in atmosphere. *(2001)*

31. The frequency order for γ-rays (B), X-rays (A),UV rays (C) is
(a) $B > A > C$ (b) $A > B > C$
(c) $C > B > A$ (d) $A > C > B$. *(2000)*

32. Ozone layer blocks the radiations of wavelength
(a) more than 3×10^{-7} m
(b) equal to 3×10^{-7} m
(c) less than 3×10^{-7} m
(d) all of these *(1999)*

33. Which of the following electromagnetic radiations have the smaller wavelength?
(a) X-rays (b) γ-rays
(c) UV waves (d) microwaves *(1994)*

34. A signal emitted by an antenna from a certain point can be received at another point of the surface in the form of
(a) sky wave (b) ground wave
(c) sea wave (d) both (a) and (b) *(1993)*

35. The structure of solids is investigated by using
(a) cosmic rays (b) X-rays
(c) γ-rays (d) infra-red radiations *(1992)*

36. Which of the following electromagnetic radiations have the longest wavelength ?
(a) X-rays (b) γ-rays
(c) Microwaves (d) Radiowaves *(1989)*

ANSWER KEY

1.	(c)	**2.**	(a)	**3.**	(c)	**4.**	(b)	**5.**	(a)	**6.**	(b)	**7.**	(a)	**8.**	(b)	**9.**	(b)	**10.**	(b)
11.	(a)	**12.**	(b)	**13.**	(a)	**14.**	(c)	**15.**	(d)	**16.**	(b)	**17.**	(a)	**18.**	(c)	**19.**	(b)	**20.**	(b)
21.	(b)	**22.**	(b)	**23.**	(c)	**24.**	(c)	**25.**	(a)	**26.**	(b)	**27.**	(a)	**28.**	(c)	**29.**	(a)	**30.**	(a)
31.	(a)	**32.**	(d)	**33.**	(b)	**34.**	(d)	**35.**	(b)	**36.**	(d)								

Hints & Explanations

1. (c) : Here, $C = 20\ \mu F$
The rate of change of potential = 3 V/s
The charge on the capacitor, $Q = CV$

$$\therefore \frac{dQ}{dt} = I_D = C\frac{dV}{dt} = 20\ \mu F \times \frac{3\ V}{s} = 60\ \mu A$$

Displacement current is equal to the conduction current.

2. (a) : Here, $R = 100\ \Omega,\ X_c = 100\ \Omega$

Net impedance, $Z = \sqrt{R^2 + X_C^2} = 100\sqrt{2}\ \Omega$

Peak value of displacement current

= Maximum conduction current in the circuit

$$= \frac{\varepsilon_0}{Z} = \frac{220\sqrt{2}}{100\sqrt{2}} = 2.2\ \text{A}$$

3. (c) : Energy received in 1 minute = Intensity × Area × Time

$E = (20\ \text{W/cm}^2) \times (20\ \text{cm}^2) \times (1 \times 60\ \text{s}) = 24 \times 10^3\ \text{J}$

4. (b) : Energy of electromagnetic wave is equally distributed in the form of electric and magnetic field energy, so ratio $\frac{U_E}{U_B} = \frac{1}{1}$.

5. (a) : Given : relative permittivity, $\varepsilon_r = 1.44$ and relative permeability, $\mu_r = 1$

Now, as we know that, $\varepsilon_r = \frac{\varepsilon}{\varepsilon_0} \Rightarrow \varepsilon = \varepsilon_r\varepsilon_0$

and $\mu_r = \frac{\mu}{\mu_0} \Rightarrow \mu = \mu_r\mu_0$

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

$\therefore$ Velocity of light in the medium will be

$$v = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{1}{\sqrt{\mu_r\mu_0\varepsilon_r\varepsilon_0}} = \frac{c}{\sqrt{\mu_r\varepsilon_r}} = \frac{3\times10^8}{\sqrt{1\times1.44}}$$

$$= 2.5\times10^8\ \text{m/s}$$

6. (b) : Velocity of em wave in a medium is given by $\vec{v} = \vec{E}\times\vec{B}$

$\therefore\ v\hat{i} = (E\hat{j})\times(\vec{B})$ $\qquad [\because\ \vec{E} = E\hat{j}\ \text{(Given)}]$

As $\hat{i} = \hat{j}\times\hat{k}$, so $\vec{B} = B\hat{k}$

Direction of oscillating magnetic field of the em wave will be along $+z$ direction.

7. (a) : Given: $E_{\text{rms}} = 6\ \text{V m}^{-1}$

$$\frac{E_{\text{rms}}}{B_{\text{rms}}} = c \text{ or } B_{\text{rms}} = \frac{E_{\text{rms}}}{c}$$

$$B_{\text{rms}} = \frac{6}{3\times10^8} = 2\times10^{-8}\ \text{T}$$

Since, $B_{\text{rms}} = \frac{B_0}{\sqrt{2}}$

where B_0 is the peak value of magnetic field.

$\therefore\ B_0 = B_{\text{rms}}\sqrt{2} = 2\times10^{-8}\times\sqrt{2}T$

$B_0 \approx 2.83\times10^{-8}\ \text{T}$

8. (b) : An accelerating charge is used to produce oscillating electric and magnetic fields, hence the electromagnetic wave.

9. (b) : Here, Energy flux, $I = 25\times10^4\ \text{W m}^{-2}$

Area, $A = 15\ \text{cm}^2 = 15\times10^{-4}\ \text{m}^2$

Speed of light, $c = 3\times10^8\ \text{m s}^{-1}$

For a perfectly reflecting surface, the average force exerted on the surface is

$$F = \frac{2IA}{c} = \frac{2\times25\times10^4\ \text{W m}^{-2}\times15\times10^{-4}\ \text{m}^2}{3\times10^8\ \text{m s}^{-1}}$$

$= 250\times10^{-8}\ \text{N} = 2.50\times10^{-6}\ \text{N}$

10. (b) : Frequency of electromagnetic wave does not change with change in medium but wavelength and velocity of wave changes with change in medium.

Velocity of electromagnetic wave in vacuum

$$c = \frac{1}{\sqrt{\mu_0\in_0}} = \upsilon\lambda_{\text{vacuum}} \qquad \text{...(i)}$$

Velocity of electromagnetic wave in the medium

$$v_{\text{medium}} = \frac{1}{\sqrt{\mu_0\mu_r\in_0\in_r}} = \frac{c}{\sqrt{\mu_r\in_r}}$$

where μ_r and $\in_r$ be relative permeability and relative permittivity of the medium.

For dielectric medium, $\mu_r = 1$

$$\therefore\ v_{\text{medium}} = \frac{c}{\sqrt{\in_r}}$$

Here, $\in_r = 4.0$

$$\therefore\ v_{\text{medium}} = \frac{c}{\sqrt{4}} = \frac{c}{2} \qquad \text{...(ii)}$$

Wavelength of the wave in medium

$$\lambda_{\text{medium}} = \frac{v_{\text{medium}}}{\upsilon} = \frac{c}{2\upsilon} = \frac{\lambda_{\text{vacuum}}}{2} \qquad \text{(Using (i) and (ii))}$$

11. (a) : Compare the given equation with

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

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

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

12. (b) : The amplitude of magnetic field and electric field for an electromagnetic wave propagating in vacuum are related as

$E_0 = B_0c$

where c is the speed of light in vacuum.

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

13. (a) : The electromagnetic wave is propagating along the $+z$ axis.

Since the electric and magnetic fields are perpendicular to each other and also perpendicular to the direction of propagation of wave.

Also, $\vec{E}\times\vec{B}$ gives the direction of wave propagation.

$\therefore\ \vec{E} = E_0\hat{i},\ B = B_0\hat{j}$ $\qquad (\because\ \hat{i}\times\hat{j} = \hat{k})$

14. (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.

15. (d) : As given

$E = 10\cos(10^7 t + kx)$ ...(i)

Comparing it with standard equation of e.m. wave,

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

Amplitude $E_0 = 10$ V/m and $\omega = 10^7$ rad/s

$\because \quad c = \upsilon\lambda = \dfrac{\omega\lambda}{2\pi}$

or $\lambda = \dfrac{2\pi c}{\omega} = \dfrac{2\pi \times 3\times 10^8}{10^7} = 188.4$ m

Also, $c = \dfrac{\omega}{k}$ or $k = \dfrac{\omega}{c} = \dfrac{10^7}{3\times 10^8} = 0.033\ \text{m}^{-1}$

The wave is propagating along $-x$ direction.

16. (b) : $E_y = 2.5\dfrac{\text{N}}{\text{C}}\left[\left(2\pi\times 10^6\dfrac{\text{rad}}{\text{m}}\right)t - \left(\pi\times 10^{-2}\dfrac{\text{rad}}{\text{s}}\right)x\right]$

$E_z = 0$ and $E_x = 0$

The wave is moving in the positive direction of x.

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

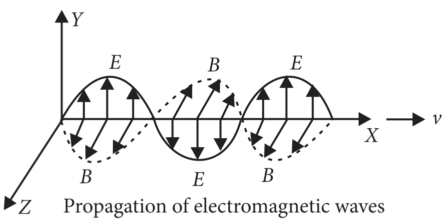
$\omega = 2\pi \times 10^6$ or $2\pi\upsilon = 2\pi \times 10^6 \Rightarrow \upsilon = 10^6$ Hz

$\dfrac{2\pi}{\lambda} = k \Rightarrow \dfrac{2\pi}{\lambda} = \pi\times 10^{-2} \Rightarrow \lambda = 2\times 10^2 = 200$ m

17. (a) : The velocity of electromagnetic radiation in vacuum is $\dfrac{1}{\sqrt{\mu_0\varepsilon_0}}$, where μ_0 and ε_0 are the permeability and permittivity of vacuum.

18. (c) : In electromagnetic wave, electric and magnetic field are in phase and perpendicular to each other and also perpendicular to the direction of the propagation of the wave.

19. (b) : According to Maxwell, the electromagnetic waves are those waves in which there are sinusoidal variation of electric and magnetic field vectors at right angles to each other as well as at right angles to the direction of wave propagation.



Propagation of electromagnetic waves

If the electric field ($\vec{E}$) and magnetic field ($\vec{B}$) are vibrating along Y and Z direction, propagation of electromagnetic wave will be along the X-axis. Therefore, the velocity of electromagnetic wave is parallel to $\vec{E}\times\vec{B}$.

20. (b) : $\lambda = \dfrac{3\times 10^8}{100\ \text{Hz}} = 3\times 10^6$ m

21. (b) : $c = \dfrac{1}{\sqrt{\mu_0\varepsilon_0}}$ (free space)

$v = \dfrac{1}{\sqrt{\mu\varepsilon}}$ (medium) $\therefore \quad \mu = \dfrac{c}{v} = \sqrt{\dfrac{\mu\varepsilon}{\mu_0\varepsilon_0}}$

22. (b) : The wave length of radiation used should be less than the size of the particle

Size of particle $= \lambda = \dfrac{c}{\upsilon}$

$3\times 10^{-4} = \dfrac{3\times 10^{10}}{\upsilon}$ or $\upsilon = 10^{14}$ hertz

However, when frequency is higher than this, wavelength is still smaller. Resolution becomes better.

23. (c) : As $\lambda = \dfrac{hc}{E}$

where the symbols have their usual meanings.

Here, $E = 15$ keV $= 15 \times 10^3$ eV and $hc = 1240$ eV nm

$\therefore \quad \lambda = \dfrac{1240\ \text{eV nm}}{15\times 10^3\ \text{eV}} = 0.083$ nm

As the wavelength range of X-rays is from 1 nm to 10^{-3} nm, so this wavelength belongs to X-rays.

24. (c) : In microwave oven, the frequency of the microwaves must match the resonant frequency of water molecules so that energy from the waves is transferred efficiently to the kinetic energy of the molecules.

25. (a) : The decreasing order of wavelength of the given electromagnetic waves is as follows:

$\lambda_{\text{Microwave}} > \lambda_{\text{Infrared}} > \lambda_{\text{Ultraviolet}} > \lambda_{\text{Gamma rays}}$

26. (b) : $\lambda_m > \lambda_v > \lambda_x$.

In spectrum X-rays has minimum wavelength and microwave has maximum wavelength.

27. (a) : Every body at all time, at all temperatures emit radiation (except at $T = 0$), which fall in the infrared region.

28. (c)

29. (a) : As the electromagnetic radiations from Sun pass through the atmosphere, some of them are absorbed by it while other reach the surface of earth. The range of wavelength which reaches earth lies in infrared region. This part of the radiation from the sun has shorter wavelength and can penetrate through the layer of gases like CO_2 and reach earth surface. But the radiation from the earth being of longer wavelength can escape through this layer. As a result the earth surface gets warm. This is known as green house effect.

30. (a) : The ozone layer absorbs the harmful ultraviolet rays coming from sun.

31. (a)

32. (d) : The range is from 380 nm to even 200 nm to 120 nm.

33. (b) **34. (d)**

35. (b) : X-rays are used for the investigation of structure of solids.

36. (d) :

Radiations	Wavelength [Range in m]
X-rays	1×10^{-11} to 3×10^{-8}
γ-rays	6×10^{-14} to 1×10^{-11}
Microwaves	10^{-3} to 0.3
Radiowaves	10 to 10^4

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