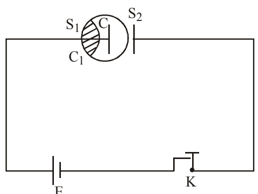
5

ELECTROMAGNETIC WAVES

DISPLACEMENT CURRENT

Consider a capacitor C, connected to a cell E and a key K, as shown in Fig. When the key is closed, a momentary current flows through the circuit. The current through the connecting wires is due to the directed flow of electrons and is called the conduction current. But there is no flow of electrons in the space between the metal plates of the capacitor. To make the current continuous through the circuit,



Maxwell argued that there is a current flowing through the dielectric region of the capacitor. He called this current as the displacement current. This is produced by a time varying electric field.

The electric field between the capacitor plates is

$E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{\varepsilon_0 A}$, where Q is the charge on the plates and A its surface area $\frac{dE}{dt} = \frac{1}{\varepsilon_0 A}\frac{dQ}{dt} = \frac{1}{\varepsilon_0 A} I_D$

The displacement current is $I_D = \varepsilon_0 A \frac{dE}{dt}$.

The current density $J_D = \frac{I_D}{A} = \frac{\varepsilon_0 dE}{dt}$.

If the medium between the plates is of dielectric constant ε, then $J_D = \varepsilon\frac{dE}{dt} = \frac{dD}{dt}$, where D is the electric displacement.

Maxwell's Correction to Ampere's Law :

According to Ampere's law $\oint \vec{B}.d\vec{\ell} = \mu_0 I$, i.e., the line integral of magnetic field around a closed loop is equal to times the current enclosed by the closed loop.

For the surface S_1 bound by the closed loop C_1,

$$\oint_{C_1} \vec{B}.d\vec{\ell} = \mu_0 I$$

For the surface S_2 bound by the same closed loop C_1,

$$\oint_{C_1} \vec{B}.d\vec{\ell} = 0$$

because there is no current enclosed by S_2. These two results for the same loop C_1 contradict each other. Maxwell solved this problem by adding a term to Ampere's law.

According to Maxwell, the line integral around a closed loop may be written as $\oint \vec{B}.d\vec{\ell} = \mu_0\left(I + \varepsilon_0 \frac{d\phi_E}{dt}\right)$,

where $\varepsilon_0 \frac{d\phi_E}{dt}$, is the displacement current. If E is the electric intensity, the ϕ_E = EA. When this equation is used, we get the correct result for the surfaces S_1 and S_2.

Characteristics of Displacement Current :

1. Displacement current has nothing to do with current, except that it adds to current density in the Ampere's law. It is called a current because it produces a magnetic field.
2. The magnitude of displacement current is equal to the rate of change of electric displacement.
3. Unlike conduction current, the displacement current exists when there is a rate of change of electric flux.
4. At points where there is an accumulation of charge and hence a discontinuity in conduction current, displacement current helps us to make the total current, continuous across the discontinuity.
5. The displacement current is negligible in a good conductor compared to the conduction current at any frequency lower than optical frequencies.
6. The addition of displacement current to Ampere's law results in the unification of electric & magnetic phenomena.

MAXWELL'S EQUATIONS

* Maxwell's equations are equations which describe the fundamental laws of electricity and magnetism.
* These equations help us to conclude that accelerating charges radiate e.m. waves and they travel with the velocity of light in free space.
* The equations, in integral form are,

1. **Gauss's law for elestrostatics :** $\oint \vec{E}.d\vec{A} = \frac{q}{\varepsilon_0}$
2. **Gauss's law for magnetism :** $\oint \vec{B}.d\vec{A} = 0$. This law tells us that the magnetic flux through any closed surface is zero. This means that magnetic monopoles do not exist.
3. **Faraday's law of electromagnetic induction**

$\oint \vec{E}.d\vec{\ell} = -\frac{d\phi_B}{dt}$, where $\frac{d\phi_B}{dt}$ is the rate of change of magnetic flux.

The law means that the line integral of electric field is equal to the potential difference (e.m.f.) e.

4. Ampere's law (with Maxwell modification :

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

$\frac{d\phi_E}{dt}$ is the rate of change of electric flux. The second term in bracket gives the displacement current.

Example 1 :

The charging current for a capacitor is 0.25 A. What is the displacement current across the plates ?

Sol. Displacement current is equal to the charging current 0.25A.

Example 2 :

A parallel plate capacitor with plate area A and seperation between the plated d, is charged by a constant current i, consider a plane surface of area A/4 parallel to the plates and drawn symetrically between the plates what is the displacement current through this area.

Sol. Electric field between the plates of the capacitor is given by $E = \frac{\sigma}{\epsilon_0}$ or $\frac{q}{A\,\epsilon_0}$. Flux through the area considered,

$$\phi = \frac{q}{A\,\epsilon_0} \times \frac{A}{4} = \frac{q}{4\,\epsilon_0}$$

Displacement current, $i_d = \epsilon_0 \frac{d\phi_E}{dt} = \epsilon_0 \times \frac{d}{dt}\left(\frac{q}{4\,\epsilon_0}\right) = \frac{i}{4}$

ELECTROMAGNETIC WAVES

* When Maxwell's four equations are solved simultaneously, it results into sinusoidal electromagnetic wave equation.
* When any of the fields (magnetic or electric) changes with time, the other field is induced in the space.
* This leads to the generation of electromagnetic disturbance comprising time varying electric and magnetic fields. Such a disturbance can be propagated through space even in the absence of any material medium.
* These disturbances have the properties of a wave and are called electromagnetic waves.
* In the year 1865, Maxwell predicted the electromagnetic waves theoretically. According to him, an accelerated charge sets up a magnetic field in its neighborhood.
* In 1887, Hertz produced and detected electromagnetic waves experimentally at wavelength of about 6 m.
* Seven year later, J.C. Bose became successful in producing EM waves of wavelength in the range 5 mm to 25mm.
* In 1896, Marconi discovered that if one of the spark gap terminals is connected to an antenna and the other terminal is earthed, the electromagnetic waves radiated could go upto several kilometers.

SIMPLE PLANE ELECTROMAGNETIC WAVE

* Electric and magnetic fields in an electromagnetic wave are perpendicular to each other, and to the direction of propagation.
* Figure shows a typical example of a plane electromagnetic wave propagating along the z direction (the fields are shown as a function of the z coordinate, at a given time t).
* The electric field E_x is along the x-axis, and varies sinusoidally with z, at a given time.
* The magnetic field B_y is along the y-axis, and again varies sinusoidally with z.
* The electric and magnetic fields E_x and B_y are perpendicular to each other, and to the direction z of propagation. We can write E_x and B_y as follows:

$E_x = E_0 \sin(kz - \omega t)$ ...... (1)

$B_y = B_0 \sin(kz - \omega t)$ ...... (2)

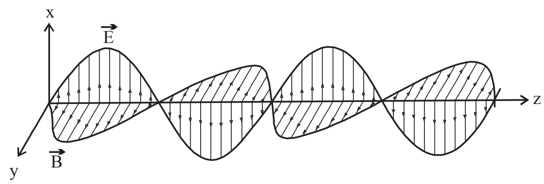


Figure : A linearly polarised electromagnetic wave, propagating in the z-direction with the oscillating electric field E along the x-direction and the oscillating magnetic field B along the y-direction.

* k is related to the wave length λ of the wave by the usual equation $k = \frac{2\pi}{\lambda}$ and ω is the angular frequency. k is the magnitude of the wave vector (or propagation vector) $\hat{k}$ and its direction describes the direction of propagation of the wave.
* The speed of propagation of the wave is (ω/k).

$$\omega = ck, \text{ where } c = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$$

* $B_0 = \frac{E_0}{c}$
* The electric and magnetic fields satisfy the following wave equations, which can be obtained from Maxwell's third and fourth equations.

$$\frac{\partial^2 E}{\partial x^2} = \mu_0\varepsilon_0 \frac{\partial^2 E}{\partial f^2} \quad ; \quad \frac{\partial^2 B}{\partial x^2} = \mu_0\varepsilon_0 \frac{\partial^2 B}{\partial t^2}$$

* Electromagnetic waves travel through vacuum with the speed of light c, where $c = \frac{1}{\sqrt{\mu_0\varepsilon_0}} = 3 \times 10^8$ m/s
* The electric and magnetic fields of an electromagnetic wave are perpendicular to each other and also perpendicular to the direction of wave propagation. Hence, these are transverse waves.
* The fundamental sources of electromagnetic waves are accelerating electric charges. For examples radio waves emitted by an antenna arise from the cotinuous oscillations (and hence acceleration) of charges within the antenna structure.
* Electromagnetic waves obey the principle of superposition.

* The electric vector of an electromagnetic field is responsible for all optical effects . For this reason electric vector is also called a light vector.

* Poynting vector, $\vec{S} = \dfrac{\vec{E} \times \vec{B}}{\mu_0}$ = Intensity (I) of wave

* Average intensity of wave
I_{av} = Average energy density × (Speed of light)

or $I_{av} = U_{av} \cdot c = \dfrac{E_0 B_0}{2\mu_0} = \dfrac{E_0^2}{2c\mu_0} = \dfrac{cB_0^2}{2\mu_0}$

* Instantaneous energy density

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

* Average energy density

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

* Energy = (momentum) . c or U = pc

* Radiation pressure

$= \dfrac{\text{Intensity}}{c}$ (when the wave is totally absorbed)

$= \dfrac{2\,(\text{Intensity})}{c}$ (when the wave is totally reflected)

DIFFERENT TYPES OF ELECTROMAGNETIC WAVES

S.N.	Name of rays	Wavelength & frequency (Hz)	Method of production / source	Properties and uses
1.	γ-rays	10^{-14} m to 10^{-10}m 3×10^{22} to 3×10^{18}	Emitted on the disintegration of nuclei of atoms.	Phosphorescence, fluorescence, polarization, diffraction, affect photographic plates, used for cancer therapy and other treatment.
2.	X-rays	10^{-13} m to 10^{-8}m 3×10^{21} to 3×10^{16}	Produced by striking high speed electrons on heavy target.	Chemical reaction on photographic plates, fluorescence, phosphorescence, ionization, etc. but less penetrating than gamma rays, used in radiography for medical diagnosis and in cancer therapy.
3.	Ultraviolet rays	6×10^{-10} m to 4×10^{-7}m 5×10^{17} to 7×10^{14}	Sun, hot vacuum, spark arc, spark and ionized gases.	All properties of gamma rays, but less penetrating, produce photoelectric effect, harmful if absorbed in large amount.
4.	Visible radiation	4×10^{-7} m to 7×10^{-7}m 4×10^{14} to 7×10^{14}	Radiated from ionized gases and incandescent bodies.	Reflection, refraction, interference, diffraction, polarization, photoelectric effect, photographic action and sensation of sight.
5.	Infrared radiation	7×10^{-7} m to 10^{-3}m 4×10^{14} to 3×10^{11}	From hot bodies	Heating effect on thermopiles and bolometer, reflection, refraction, diffraction, photographic action, used in physical therapy. Also, called heat wave.
6.	Micro-waves	10^{-4} m to 1m 3×10^{12} to 3×10^{8}	Produced by spark discharge.	They are reflected, refracted and produce spark in the gaps of receiving circuits. Wave of wavelengths from 10^{-3} to 3×10^{-2}m are also called 'microwaves' used in radar and satellite communication.
7.	Long radio or wireless waves	10^{-2} m to 10^{4}m 3×10^{10} to 3×10^{4}	From spark gap discharges and oscillating electric circuits.	They are reflected, refracted and diffracted, used in radio and TV communication.

TRY IT YOURSELF

Q.1 The charge of a parallel plate capacitor is varying

$q = q_0 \sin 2\pi ft$. The plates are very large and close together (area = A, separation = d). Neglecting edge effect, the displacement current through the capacitor is –

(A) $\frac{q}{A\varepsilon_0}$ (B) $\frac{q_0}{\varepsilon_0}\sin 2\pi ft$

(C) $2\pi f q_0 \cos 2\pi ft$ (D) $\frac{2\pi f q_0}{\varepsilon_0}\cos 2\pi ft$

Q.2 A parallel plate capacitor consists of two circular plates each of radius 2cm, separated by a distance of 0.1mm. If voltage across the plates is varying at the rate of

5×10^{13} volt/s, then the value of displacement current is

(A) 5560 A (B) 5.56 A

(C) 5.56 mA (D) 556 A

Q.3 In a plane electromagnetic wave, the electric field oscillates sinusoidally at a frequency 2×10^{10} Hz and amplitude

60V/m. Calculate (a) Wavelength of wave (b) Amplitude of the oscillation magnetic field.

Q.4 EM waves travel in a medium which has relatively permeability 1.3 and relative permittivity 2.14. Speed of EM wave in this medium will be –

(A) 1.8×10^5 m/s (B) 1.8×10^6 m/s

(A) 1.8×10^7 m/s (A) 1.8×10^8 m/s

Q.5 The sun radiates electromagnetic energy at the rate of

3.9×10^{26} watt. Its radius is 6.96×10^8 m. What will be the intensity of sunlight at the solar surface?

Q.6 In a plane electromagnetic wave, the electric field oscillate with 20 V/m. Find (a) Average energy density of electric field (b) Average energy density of magnetic field.

Q.7 A microwave and an ultrasonic wave have some wavelength. What is the ratio of their frequency.

Q.8 Light with an energy flux of 20 W/cm^2 falls on a non-reflecting surface at normal incidence. If the surface has an area of 30 cm^2. the total momentum delivered (for complete absorption) during 30 minutes is

(A) 36×10 kg m/s. (B) 36×10^{-4} kg m/s.

(C) 108×10^4 kg m/s. (D) 1.08×10^7 kg m/s.

Q.9 The ratio of contributions made by the electric field and magnetic field components to the intensity of an EM wave

(A) c : 1 (B) $c^2 : 1$

(C) 1 : 1 (D) $\sqrt{c} : 1$

Q.10 A plane electromagnetic wave propagating along x direction can have the following pairs of E and B

(A) E_x, B_y (B) E_y, B_z

(C) B_x, E_y (D) E_z, B_y

ANSWERS

(1) (C) **(2)** (A) **(3)** (a) 1.5×10^{-2} m, (b) 2×10^{-7} T

(4) (D) **(5)** 5.6×10^7 watt/m^2

(6) (a) 8.85×10^{-10} J/m^3, (b) 8.85×10^{-10} J/m^3

(7) 10^6 Hz **(8)** (B) **(9)** (C) **(10)** (BD)

USEFUL TIPS

* The vector product $\vec{E} \times \vec{B}$ always points in the direction of propagation.
* Remember : $\hat{i} \times \hat{j} = \hat{k}$; $\hat{j} \times \hat{k} = \hat{i}$; $\hat{k} \times \hat{i} = \hat{j}$
* The EM wave requires no medium.
* EM waves have the property of polarisation.

ADDITIONAL EXAMPLES

Example 1 :

The sun light strikes the upper atmosphere of earth with intensity 1.38 Kw/m^2. Find the peak value of electric field at that point.

Sol. The intensity of light $I = \langle S \rangle = \frac{1}{2\mu_0 c} \times E_0^2$

$$E_0 = \sqrt{2\mu_0 c I} = \sqrt{2 \times 4\pi 10^{-7} \times 3 \times 10^8 \times 1.38 \times 10^3}$$

= 1.02 Kilovolt/meter

Example 2 :

Find the ratio of the pressure exerted by electromagnetic waves on reflecting surface and the absorbing surface.

Sol. $\langle P_r \rangle = \frac{2}{3}\langle U \rangle$ ....(1) $\langle P_a \rangle = \frac{\langle U \rangle}{3}$ ....(2)

From eqn. (1) and (2), $\frac{\langle P_r \rangle}{\langle P_a \rangle} = 2$

QUESTION BANK

CHAPTER 5 : ELECTROMAGNETIC WAVES

EXERCISE - 1 [LEVEL-1]

Choose one correct response for each question.

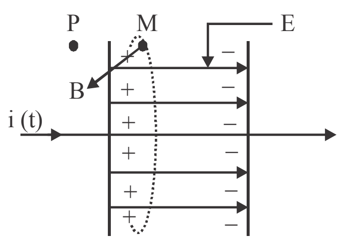
PART 1 : DISPLACEMENT CURRENT

Q.1 A parallel plate capacitor with plate area A and seperation between the plated d, is charged by a constant current i, consider a plane surface of area A/4 parallel to the plates and drawn symetrically between the plates what is the displacement current through this area.
(A) i (B) 2i
(C) i/4 (D) i/2

Q.2 The charge on a parallel plate capacitor varies as $q = q_0 \cos 2\pi\nu t$. The plates are very large and close together (area = A, separation = d). The displacement current through the capacitor is
(A) $q_0\, 2\pi\nu \sin\pi\nu t$ (B) $-q_0\, 2\pi\nu \sin 2\pi\nu t$
(C) $q_0\, 2\pi \sin\pi\nu t$ (D) $q_0\, \pi\nu \sin 2\pi\nu t$

Q.3 The total current passing through any surface, of which the closed loop is the perimeter, is –
(A) sum of conduction current and displacement current.
(B) difference of conduction current and displacement current.
(C) product of conduction current and displacement current.
(D) fraction of conduction current and displacement current.

Q.4 In the given figure, a magnetic field (say at point M) between the plates of the capacitor to be the same as that just –



(A) outside at P (B) between the plates
(C) above the plates (D) down the plates

Q.5 If a variable frequency ac source is connected to a capacitor then with decrease in frequency the displacement current will –
(A) increase (B) decrease
(C) remains constant (D) first decrease then increase

Q.6 The charging current for a capacitor is 1 A then what is the displacement current ?
(A) 1 A (B) 0.5 A
(C) 0 (D) 2 A

Q.7 Displacement current goes through the gap between the plates of a capacitor when the charge on the capacitor
(A) is changing with time.
(B) decreases.
(C) does not change.
(D) decreases to zero.

PART 2 : ELECTROMAGNETIC WAVES

Q.8 The electromagnetic waves do not transport
(A) Energy (B) Charge
(C) Momentum (D) Information

Q.9 If E and B be the electric and magnetic field of E.M. wave then the direction of propogation of E.M. wave is along the direction.
(A) $\vec{E}$ (B) $\vec{B}$
(C) $\vec{E} \times \vec{B}$ (D) $\vec{B} \times \vec{E}$

Q.10 Which of the following pairs of space and time varying E and B fields would generate a plane electromagnetic wave travelling in (–Z) direction-
(A) E_x, B_y (B) E_y, B_x
(C) E_x, B_y (D) E_y, B_x

Q.11 Choose the wrong statement for E.M. wave. They-
(A) Are Transverse
(B) Travels in free space with the speed of light
(C) Are produced by accelerated charges
(D) Travels with same speed in all medium

Q.12 Light is an electromagnetic wave. Its speed in vacuum is given by the expression
(A) $\sqrt{\mu_o \varepsilon_o}$ (B) $\sqrt{\dfrac{\mu_o}{\varepsilon_o}}$
(C) $\sqrt{\dfrac{\varepsilon_o}{\mu_o}}$ (D) $\dfrac{1}{\sqrt{\mu_o \varepsilon_o}}$

Q.13 The electric field of an electromagnetic wave travelling through vacuum is given by the equation $E = E_0 \sin(kx - \omega t)$. The quantity that is independent of wavelength is –
(A) $k\omega$ (B) k/ω
(C) $k^2\omega$ (D) ω

Q.14 A plane electromagnetic wave travels in vacuum along z-direction. If the frequency of the wave is 40 MHz then its wavelength is –
(A) 5m (B) 7.5 m
(C) 8.5 m (D) 10 m

Q.15 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) $p \neq 0, E = 0$

Q.16 An electromagnetic wave going through vacuum is described by $E = E_0 \sin(kx - \omega t)$; $B = B_0 \sin(kx - \omega t)$. Which of the following equation is true
(A) $E_0 k = B_0 \omega$ (B) $E_0 \omega = B_0 k$
(C) $E_0 B_0 = \omega k$ (D) None

Q.17 A charged paritcle oscillate about its mean equilibrium position with a frequency of 10^9 Hz. The frequency of electromagnetic waves produced by the oscillator is –
(A) 10^6 Hz (B) 10^7 Hz
(C) 10^8 Hz (D) 10^9 Hz

Q.18 The amplitude of an electromagnetic wave in vacumm 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

Q.19 An electromagnetic wave propagating along north has its electric field vector upwads. Its magnetic field vector point towards –
(A) north (B) east
(C) west (D) downwards

Q.20 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.

PART 3 : ELECTROMAGNETIC SPECTRUM

Q.21 TV transmission is possible by-
(A) Ground wave (B) Sky wave
(C) space wave (D) None

Q.22 The range of wavelength of the visible light is
(A) 10 Å to 100 Å (B) 4,000 Å to 7,000 Å
(C) 8,000 Å to 10,000 Å (D) 10,000 Å to 15,000 Å

Q.23 Which radiation in sunlight, causes heating effect
(A) Ultraviolet (B) Infrared
(C) Visible light (D) All of these

Q.24 Electromagnetic radiation of highest frequency is
(A) Infrared radiations (B) Visible radiation
(C) Radio waves (D) γ-rays

Q.25 Which of the following shows green house effect
(A) Ultraviolet rays (B) Infrared rays
(C) X-rays (D) None of these

Q.26 Radio waves and visible light in vacuum have
(A) Same velocity but different wavelength
(B) Continuous emission spectrum
(C) Band absorption spectrum
(D) Line emission spectrum

Q.27 In which one of the following regions of the electromagnetic spectrum will the vibrational motion of molecules give rise to absorption
(A) Ultraviolet (B) Microwaves
(C) Infrared (D) Radio waves

Q.28 TV waves have a wavelength range of 1-10 meter. Their frequency range in MHz is –
(A) 30-300 (B) 3-30
(C) 300-3000 (D) 3-3000

Q.29 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)

Q.30 Infrared waves are produced by –
(A) hot bodies and molecules.
(B) cold bodies and molecules.
(C) neither hot nor cold.
(D) both (A) and (B).

Q.31 I. Ultraviolet rays wavelength ranging about 4×10^{-7}m (400 nm) down to 6×10^{-10}m (0.6 nm).
II. UV radiation is produced by special lamps and very hot bodies.
III. The sun is an important source of ultraviolet light.
IV. Most of the UV rays absorbed in the ozone layer in the atmosphere at an altitude of about 40-50 km.
Which of the following statements are correct.
(A) I, II and III (B) II, III and IV
(C) I, III and IV (D) All of these

Q.32 In the electromagnetic spectrum, X-ray region lies –
(A) beyond the microwave region.
(B) above the ultraviolet region
(C) beyond the UV region
(D) above the infrared ray region.

Q.33 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

Q.34 Which of the following electromagnetic wave is used in high precision application like LASIK eye surgery?
(A) Microwave (B) Ultraviolet rays
(C) Gamma rays (D) X-rays

Q.35 The waves used by artificial satellites for communication is –
(A) microwaves (B) infrared waves
(C) radio waves (D) X-rays

Q.36 If v_g, v_X and v_m are the speeds of gamma rays, X-rays and microwaves respectively in vacuum, then –
(A) $v_g < v_X < v_m$ (B) $v_g > v_X > v_m$
(C) $v_g > v_X < v_m$ (D) $v_g = v_X = v_m$

Q.37 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

EXERCISE - 2 (LEVEL-2)

Choose one correct response for each question.

Q.1 Electromagnetic waves travel in a medium which has relative permeability 1.3 and relative permittivity 2.14. Then the speed of the electromagnetic wave in the medium will be
(A) 13.6×10^6m/s (B) 1.8×10^2m/s
(C) 3.6×10^8m/s (D) 1.8×10^8m/s

Q.2 The intensity of light from a source is $(500/\pi)$ W/m^2. Find the amplitude of electric field in this wave-

(A) $\sqrt{3} \times 10^2$ N/C (B) $2\sqrt{3} \times 10^2$ N/C

(C) $\frac{\sqrt{3}}{2} \times 10^2$ N/C (D) $2\sqrt{3} \times 10^1$ N/C

Q.3 In a EM wave the amplitude of electric field is 10 V/m. The frequency of wave is 5×10^4 Hz. The wave is propogating along Z-axis. Then the average energy density of Magnetic field is-

(A) 2.21×10^{-10} J/m^3 (B) 2.21×10^{-8} J/m^3
(C) 2×10^{-8} J/m^3 (D) 2×10^{-10} J/m^3

Q.4 Elecromagnetic waves travel in a medium with a speed of 2×10^8 m/s. The relative permeability of the medium is 1. What is the relative permittivity of the medium –

(A) 2.25 (B) 1.25
(C) 3.25 (D) 0.25

Q.5 If a source is transmitting electromagnetic wave of frequency 8.2×10^6 Hz, then wavelength of the electromagnetic waves transmitted from the source will be

(A) 36.5 m (B) 40.5 m
(C) 42.3 m (D) 50.9 m

Q.6 In an apparatus, the electric field was found to oscillate with an amplitude of 18 V/m. The magnitude of the oscillating magnetic field will be

(A) 4×10^{-6} T (B) 6×10^{-8} T
(C) 9×10^{-9}T (D) 11×10^{-11} T

Q.7 A radio receiver antenna that is 2 m long is oriented along the direction of the electromagnetic wave and receives a signal of intensity 5×10^{-16} W/m^2. The maximum instantaneous potential difference across the two ends of the antenna is

(A) 1.23 μV (B) 1.23 mV
(C) 1.23 V (D) 12.3 mV

Q.8 The sun light strikes the upper atmosphere of earth with intensity 1.38 Kw/m^2. The peak value of electric field at that point will be-
(in kilovolt/meter)

(A) 2.04 (B) 4.08
(C) 8.16 (D) 1.02

Q.9 The ratio of the pressure exerted by electromagnetic waves on reflecting surface and the absorbing surface will be -

(A) 2 : 1 (B) 1 : 2
(C) 3 : 1 (D) 1 : 3

Q.10 I. Maxwell's equations that electric and magnetic fields in an electromagnetic wave are perpendicular to each other and to the direction of propagation.

II. The electric field inside the plates of the capacitor is directed perpendicular to the plates.

III. The magnetic field due to displacement current is along the perimeter of a circle parallel to the capacitor plates. So, B and E are perpendicular in this case.

Which of the above statements is/are correct?

(A) I and II (B) II and III
(C) I and III (D) All of these

Q.11 A radio can tune to any station in 7.5 MHz to 12MHz 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

Q.12 A plane electromagnetic wave of frequency 25MHz travels in free space along x-direction. At a particular point in space and time, electric E = 6.3 Vm^{-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

Q.13 Radiations of intensity 0.5 Wm^{-2} are striking a metal plate. The pressure (in Nm^{-2})on the plate

(A) 0.166×10^{-8} (B) 0.332×10^{-8}
(C) 0.111×10^{-8} (D) 0.083×10^{-8}

Q.14 An electromagnetic radiation has an energy of 13.2 keV. Then the radiation belongs to the region

(A) visible light (B) ultraviolet
(C) infrared (D) X-ray

Q.15 I. Wavelength of microwaves is greater than that of ultraviolet rays.

II. The wavelength of infrared rays is lesser than that of ultraviolet rays.

III. The wavelength of microwave is lesser than that of infrared rays.

IV. Gamma rays has shortest wavelength in the electromagnetic spectrum.

Choose the correct option from the given options

(A) I and II are true (B) II and III are true
(C) III and IV are true (D) I and IV are true

Q.16 I. The total current i is the sum of the condensation current denoted by i_c, and the displacement current denoted by $i_d(t) = \varepsilon_0 (d\phi_E/dt)$.

$$\text{So, } i = i_e + i_d = i_c + \varepsilon_0 \frac{d\phi_\varepsilon}{dt}$$

II. Outside the capacitor plates, we have only conduction current $i_c = i$ and no displacement current, $i_d = 0$

III. Inside the capacitor, there is no conduction current $i_c = 0$ and there is only displacement current, so that $i_d = i$.

Which of the above statements is/are correct?

(A) I and II (B) II and III
(C) I and III (D) All of these

EXERCISE - 3 [PREVIOUS YEARS AIEEE / JEE MAIN QUESTIONS]

Q.1 Electromagnetic waves are transverse in nature is evident by – **[AIEEE 2002]**
(A) polarization (B) interference
(C) reflection (D) diffraction

Q.2 Which of the following are not electromagnetic waves? **[AIEEE 2002]**
(A) cosmic rays (B) gamma rays
(C) beta - rays (D) X- rays

Q.3 Which of the following radiations has the least wavelength **[AIEEE 2003]**
(A) β-rays (B) α-rays
(C) X-rays (D) γ -rays

Q.4 A radiation of energy E falls normally on a perfectly reflecting surface. The momentum transferred to the surface is – **[AIEEE 2004]**
(A) E/c (B) 2E/c
(C) E/c (D) E/c^2

Q.5 An electromagnetic wave of frequency ν = 3.0 MHz passes from vacuum into a dielectric medium with permittivity $\varepsilon = 4.0$. Then **[AIEEE 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.

Q.6 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– **[AIEEE 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

Q.7 An electromagnetic wave in vacuum has the electric and magnetic field $\vec{E}$ and $\vec{B}$, which are always perpendicular to each other. The direction of polarization is given by $\vec{X}$ and that of wave propagation by $\vec{k}$. Then **[AIEEE 2012]**
(A) $\vec{X} \parallel \vec{B}$ & $\vec{k} \parallel \vec{B} \times \vec{E}$ (B) $\vec{X} \parallel \vec{E}$ & $\vec{k} \parallel \vec{E} \times \vec{B}$
(C) $\vec{X} \parallel \vec{B}$ & $\vec{k} \parallel \vec{E} \times \vec{B}$ (D) $\vec{X} \parallel \vec{E}$ & $\vec{k} \parallel \vec{B} \times \vec{E}$

Q.8 The magnetic field in a travelling electromagnetic wave has a peak value of 20 nT. The peak value of electric field strength is – **[JEE MAIN 2013]**
(A) 3V/m (B) 6V/m
(C) 9V/m (D) 12 V/m

Q.9 Match the column – **[JEE MAIN 2014]**

List – I	List – II
(a) Infrared waves	(i) To treat muscular strain
(b) Radio waves	(ii) For broadcasting
(c) X-rays	(iii) To detect fracture of bones
(d) Ultraviolet rays	(iv) Absorbed by the ozone layer of the atmosphere.

(A) (a) - iii, (b) - ii, (c) - i, (d) iv
(B) (a) - i, (b) - ii, (c) - iii, (d) iv
(C) (a) - iv, (b) - iii, (c) - ii, (d) i
(D) (a) - i, (b) - ii, (c) - iv, (d) iii

Q.10 During the propagation of electromagnetic waves in a medium: **[JEE MAIN 2014]**
(A) Electric energy density is equal to the magnetic energy density.
(B) Both electric and magnetic energy densities are zero.
(C) Electric energy density is double of the magnetic energy density.
(D) Electric energy density is half of the magnetic energy density.

Q.11 Arrange the following electromagnetic radiations per quantum in the order of increasing energy :
A : Blue light , B : Yellow light, C : X-ray, D : Radiowave **[JEE MAIN 2016]**
(A) A, B, D, C (B) C, A B, D
(C) B, A, D, C (D) D, B, A, C

Q.12 An EM wave from air enters a medium. The electric fields are $\vec{E}_1 = E_{01}\hat{x}\cos\left[2\pi\nu\left(\frac{z}{c} - t\right)\right]$ in air and $\vec{E}_2 = E_{02}\hat{x}\cos[k(2z - ct)]$ in medium, where the wave number k and frequency ν refer to their values in air. The medium is non-magnetic. If ε_{r_1} and ε_{r_2} refer to relative permittivities of air and medium respectively, which of the following options is correct? **[JEE MAIN 2018]**
(A) $\frac{\varepsilon_{r_1}}{\varepsilon_{r_2}} = \frac{1}{4}$ (B) $\frac{\varepsilon_{r_1}}{\varepsilon_{r_2}} = \frac{1}{2}$ (C) $\frac{\varepsilon_{r_1}}{\varepsilon_{r_2}} = 4$ (D) $\frac{\varepsilon_{r_1}}{\varepsilon_{r_2}} = 2$

Q.13 A plane electromagnetic wave of frequency 50 MHz travels in free space along the positive x-direction. At a particular point in space and time, $\vec{E} = 6.3\,\hat{j}$ V / m. The corresponding magnetic field $\vec{B}$, at that point will be : **[JEE MAIN 2019(JAN)]**
(A) $18.9 \times 10^{-8}\,\hat{k}$ T (B) $6.3 \times 10^{-8}\,\hat{k}$ T
(C) $2.1 \times 10^{-8}\,\hat{k}$ T (D) $18.9 \times 10^{8}\,\hat{k}$ T

Q.14 A plane electromagnetic wave travels in free space along the x-direction. The electric field component of the wave at a particular point of space and time is E = 6 V m^{-1} along y-direction. Its corresponding magnetic field component, B would be : **[JEE MAIN 2019 (APRIL)]**
(A) 6×10^{-8} T along z-direction
(B) 6×10^{-8} T along x-direction
(C) 2×10^{-8} T along z-direction
(D) 2×10^{-8} T along y-direction

Q.15 If the magnetic field in a plane electromagnetic wave is given by $B = 3 \times 10^{-8} \sin(1.6 \times 10^3 x + 48 \times 10^{10} t)\hat{j}T$, then what will be expression for electric field?

[JEE MAIN 2020 (JAN)]

(A) $\vec{E} = (9 \sin(1.6 \times 10^3 x + 48 \times 10^{10} t)\,\hat{k}\ V/m)$

(B) $\vec{E} = (3 \times 10^{-8} \sin(1.6 \times 10^3 x + 48 \times 10^{10} t)\,\hat{i}\ V/m)$

(C) $\vec{E} = (60 \sin(1.6 \times 10^3 x + 48 \times 10^{10} t)\,\hat{k}\ V/m)$

(D) $\vec{E} = (3 \times 10^{-8} \sin(1.6 \times 10^3 x + 48 \times 10^{10} t)\,\hat{j}\ V/m)$

Q.16 A plane electromagnetic wave of frequency 25 GHz is propagating in vacuum along the z-direction. At a particular point in space and time, the magnetic field is given by $\vec{B} = 5 \times 10^{-8}\hat{j}T$. The corresponding electric field $\vec{E}$ is

(Speed of light $c = 3 \times 10^8\ ms^{-1}$) **[JEE MAIN 2020 (JAN)]**

(A) $1.66 \times 10^{-16}\ \hat{i}\ V/m$
(B) $15\ \hat{i}\ V/m$
(C) $-1.66 \times 10^{-16}\ \hat{i}\ V/m$
(D) $-15\hat{i}\ V/m$

EXERCISE - 4 [PREVIOUS YEARS AIPMT / NEET QUESTIONS]

Q.1 If λ_v, λ_x & λ_m respresent the wavelengts of visible light, X-rays and microwaves respectively, then **[AIPMT 2005]**

(A) $\lambda_m > \lambda_x > \lambda_v$ (B) $\lambda_m > \lambda_v > \lambda_x$

(C) $\lambda_v > \lambda_x > \lambda_m$ (D) $\lambda_v > \lambda_m > \lambda_x$

Q.2 The velocity of electromagnetic radiation in a medium of permittivity ε_0 and permeability μ_0 is given by **[AIPMT 2008]**

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

Q.3 The electric field part of an electromagnetic wave in a medium is represented by $E_x = 0$;

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

$E_z = 0$. The wave is: **[AIPMT 2009]**

(A) moving along x direction with frequency 10^6 Hz and wave length 100 m.

(B) moving along x direction with frequency 10^6 Hz and wave length 200 m.

(C) moving along –x direction with frequency 10^6 Hz and wave length 200 m.

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

Q.4 Which of the following statement is false for the properties of electromagnetic waves? **[AIPMT 2010]**

(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 perpendicular to the direction of propagation of wave.

(D) These waves do not require any material medium for propagation.

Q.5 The decreasing order of wavelength of infrared, microwave, ultraviolet and gamma rays is **[AIPMT 2011]**

(A) Infrared, microwave, ultraviolet, gamma rays.

(B) Microwave, infrared, ultraviolet, gamma rays.

(C) Gamma rays, ultraviolet, infrared, microwaves.

(D) Microwaves, gamma rays, infrared, ultraviolet.

Q.6 The electric and the magnetic field, associated with an e.m. wave, propagating along the +z-axis, can be represented by – **[AIPMT 2011]**

(A) $[\vec{E} = E_0\hat{j}, \vec{B} = B_0\hat{k}]$ (B) $[\vec{E} = E_0\hat{i}, \vec{B} = B_0\hat{j}]$

(C) $[\vec{E} = E_0\hat{k}, \vec{B} = B_0\hat{i}]$ (D) $[\vec{E} = E_0\hat{j}, \vec{B} = B_0\hat{i}]$

Q.7 The electric field associated with an e.m. wave in vacuum is given by $\vec{E} = \hat{i}\,40\cos(kz - 6\times10^8 t)$, where E, z and t are in volt/m, meter and seconds respectively. The value of wave vector k is : **[AIPMT 2012]**

(A) 2 m^{-1} (B) 0.5 m^{-1}

(C) 6 m^{-1} (D) 3 m^{-1}

Q.8 The condition under which a microwave oven heats up a food item containing water molecules most efficiently is **[NEET 2013]**

(A) Infra-red waves produce heating in a microwave oven.

(B) The frequency of the microwaves must match the resonant frequency of the water molecules.

(C) The frequency of the microwaves has no relation with natural frequency of water molecules.

(D) Microwaves are heat waves, so always produce heating.

Q.9 The energy of the em waves is of the order of 15keV. To which part of the spectrum does it belong? **[RE-AIPMT 2015]**

(A) γ-rays (B) X-rays

(C) Infra-red rays (4) Ultraviolet rays

Q.10 Which one can be used to produce a propagating electromagnetic wave? **[NEET 2016 PHASE 1]**

(A) A charge moving at constant velocity.

(B) A stationary charge

(C) A chargeless particle

(D) An accelerating charge

Q.11 A 100 Ω resistance and a capacitor of 100Ω reactance are connected in series across a 220 V source. When the capacitor is 50% charged, the peak value of the displacement current is – **[NEET 2016 PHASE 2]**

(A) 2.2 A (B) 11 A

(C) 4.4 A (D) $11\sqrt{2}$ A

Q.12 In an electromagnetic wave in free space the root mean square value of the electric field is E_{rms} = 6V/m. The peak value of the magnetic field is – **[NEET 2017]**

(A) 2.83×10^{-8} T (B) 0.70×10^{-8} T

(C) 4.23×10^{-8} T (D) 1.41×10^{-8} T

Q.13 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 **[NEET 2018]**

(A) –y direction (B) +z direction

(C) –z direction (D) –x direction

Q.14 Which colour of the light has the longest wavelength? **[NEET 2019]**

(A) Red (B) Blue

(C) Green (D) Violet

ANSWER KEY

EXERCISE - 1

Q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
A	C	B	A	A	B	A	A	B	C	B	D	D	B	B	A	A	D	D	B	B	C	B	B	D	B
Q	26	27	28	29	30	31	32	33	34	35	36	37													
A	A	B	A	D	A	D	B	D	B	A	D	C													

EXERCISE - 2

Q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	D	B	A	A	A	B	A	D	A	D	A	D	A	B	D	D

EXERCISE - 3

Q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	A	B	D	B	C	B	B	B	B	A	D	A	C	C	A	B

EXERCISE - 4

Q	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	D	B	C	B	B	A	B	B	D	A	A	B	A

ELECTROMAGNETIC WAVE

TRY IT YOURSELF

(1) **(C).** $I_0 = \frac{dq}{dt} = \frac{d}{dt}(q_0 \sin 2\pi ft) = q_0 2\pi ft \cos 2\pi ft$

$= 2\pi f q_0 \cos 2\pi ft$

(2) **(A).** $I_D = C\frac{dv}{dt} = \frac{\varepsilon_0 A}{d}\frac{dv}{dt}$

(3) (a) $\lambda = \frac{c}{v} = \frac{3\times10^8}{2\times10^{10}} = 1.5\times10^{-2}\,m$

(b) $B_0 = \frac{E_0}{C} = \frac{60}{3\times10^8} = 20\times10^{-8} = 2\times10^{-7}\,T$

(4) **(D).** In a medium speed $= \frac{1}{\sqrt{\varepsilon_0\varepsilon_r\,\mu_0\mu_r}} = \frac{c}{\sqrt{\mu_r\varepsilon_r}}$

(5) Intensity $I = \frac{P}{A} = \frac{3.9\times10^{26}}{4\pi r^2} = \frac{3.9\times10^{26}}{4\times3.14\times(6.96\times10^8)^2}$

$= 5.6\times10^7$ watt/m^2

(6) (a) Any energy density of electric field

$$U_E = \frac{1}{2}\varepsilon_0 E_{rms}^2 = \frac{1}{2}\varepsilon_0\left(\frac{E_0}{\sqrt{2}}\right) = \frac{1}{4}\varepsilon_0 E_0^2$$

$$= \frac{1}{4}\times8.85\times10^{-12}\times(20)^2 = 8.85\times10^{-10}\,J/m^3$$

(b) Average energy density of magnetic field

$$= \frac{E_{rms}^2}{2\mu_0} = \frac{(B_0/\sqrt{2})^2}{2\mu_0} = \frac{1}{4}\frac{B_0^2}{\mu_0} = \frac{1}{4}\varepsilon_0 E_0^2$$

$$= \frac{1}{4}\times8.85\times10^{-12}\times(20)^2 = 8.85\times10^{-10}\,J/m^3$$

(7) Microwave are of frequency $\nu_m = 10^{11}$ Hz ultrasonic sound is of frequencies $\nu_u = 10^5$ Hz then

$$\frac{\nu_m}{\nu_u} = \frac{10^{11}}{10^5} = 10^6\,Hz$$

(8) (B)

(9) (C)

(10) (BD)

CHAPTER- 5 : ELECTROMAGNETIC WAVES
EXERCISE-1

(1) **(C).** Electric field between the plates of the capacitor is given by $E = \frac{\sigma}{\epsilon_0}$ or $\frac{q}{A\epsilon_0}$

Flux through the area considered

$$\phi = \frac{q}{A\epsilon_0} \times \frac{A}{4} = \frac{q}{4\epsilon_0}$$

Displacement current

$$i_d = \epsilon_0 \frac{d\phi_E}{dt} = \epsilon_0 \times \frac{d}{dt}\left(\frac{q}{4\epsilon_0}\right) = \frac{i}{4}$$

(2) **(B).** Displacement current,
I_D = conduction current, I_C

$$\frac{dq}{dt} = \frac{d}{dt}[q_0 \cos 2\pi\nu t] = -q_0 2\pi\nu \sin 2\pi\nu t$$

(3) **(A).** The total current passing through any surface of which the closed loop is the perimeter is the sum of conduction current and displacement current. The generalised law is $\oint B \cdot d\ell = \mu_0 i_c + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$

and is known as Ampere-Maxwell law.

(4) **(A).** A magnetic field (say at point M) between the plates of the capacitor to be the same as that just outside at P.

(5) **(B).** Current through capacitor

$$I = \frac{E}{X_c} = \frac{E}{1/\omega C} = \omega CE = 2\pi\nu cE \quad \text{or } I \propto \nu.$$

Decreases in frequency ac source decreases the conduction current. As displacement current is equal to conduction current, decrease in ν decreases displacement current in circuit.

(6) **(A).** Electric field between the plates is

$$E = \frac{Q}{\epsilon_0 A} \quad \therefore \phi_E = E.A = \frac{Q}{\epsilon_0 A} \times A$$

$$\therefore i_d = \epsilon_0 \frac{d\phi_E}{dt} = \epsilon_0 \frac{d}{dt}\left(\frac{Q}{\epsilon_0}\right)$$

$$\therefore i_d = \frac{dQ}{dt} = i \text{ (charging current). Hence } i_d = 1A$$

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

(8) **(B).** EM waves transport energy, momentum and information but not charge. EM waves are uncharged

(9) **(C).** The direction of propagation of electromagnetic wave is perpendicular to both electric field vector $\vec{E}$ and magnetic field vector $\vec{B}$ i.e. in the direction of $\vec{E} \times \vec{B}$

(10) **(B).** Since the direction of propogation of EM wave is given by $E \times B$ $\quad \therefore (\hat{j} \times \hat{i} = -\hat{k})$

(11) **(D).** Speed of E.M. wave $= \frac{1}{\sqrt{\mu_0 \in \mu_r \in_r}}$

in medium hence it will travel with different speed in different medium.

(12) **(D).** $\mu_0 = 4\pi \times 10^{-7}$; $\varepsilon_0 = 8.85 \times 10^{-12} \frac{N\text{-}m^2}{C^2}$

so $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3 \times 10^8 \frac{\text{meter}}{\text{sec}}$.

(13) **(B).** Here, $k = \frac{2\pi}{\lambda}$, $\omega = 2\pi\nu$

$$\frac{k}{\omega} = \frac{2\pi/\lambda}{2\pi\nu} = \frac{1}{\nu\lambda} = \frac{1}{c} \quad (\because c = \nu\lambda)$$

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

(14) **(B).** Wavelength, $\lambda = \frac{c}{\nu} = \frac{3 \times 10^8 \text{ m/s}}{40 \times 10^6 \text{ s}^{-1}} = 7.5$ m

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

(16) **(A).** $\frac{E_0}{B_0} = C$. Also $k = \frac{2\pi}{\lambda}$ and $\omega = 2\pi\nu$

These relation gives $E_0 K = B_0 \omega$

(17) **(D).** The frequency of electromagnetic wave is the same as that of oscillating charged particle about its equilibrium position, which is 10^9 Hz.

(18) **(D).** Velocity of electromagnetic wave

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

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

(19) **(B).** An electromagnetic wave propagating along north has its electric field vector upwads. Its magnetic field vector point towards east.

(20) **(B).** The amplitudes of electric field and magnetic field for an electromagnetic wave propagating in vacuum are related as $E_0 = B_0 c$, where c is the speed of light in vacuum. $\frac{B_0}{E_0} = \frac{1}{c}$

(21) **(C).** TV transmission is possible by space wave.

(22) **(B).** Wavelength of visible spectrum is 4000 Å – 7000 Å.

(23) **(B).** Infrared causes heating effect.

(24) **(D).** $\nu_{\gamma-\text{rays}} > \nu_{\text{visible radiation}} > \nu_{\text{Infrared}} > \nu_{\text{Radio waves}}$

(25) **(B).** Infrared radiations reflected by low lying clouds and keeps the earth warm.

(26) **(A).** In vacuum velocity of all EM waves are same but their wavelengths are different.

(27) **(B).** Molecular spectra due to vibrational motion lie in the microwave region of EM-spectrum. Due to Kirchhoff's law in spectroscopy the same will be absorbed.

(28) **(A).** $\nu = \frac{C}{\lambda} \Rightarrow \nu_1 = \frac{3\times10^8}{1} = 3\times10^8\,\text{Hz} = 300\text{ MHz}$

and $\nu_2 = \frac{3\times10^8}{10} = 3\times10^7\,\text{Hz} = 30\text{ MHz}$

(29) **(D).** Ground wave and sky wave both are amplitude modulated wave and the amplitude modulated signal is transmitted by a transmitting antenna and received by the receiving antenna at a distance place.

(30) **(A).** Infrared waves are produced by the hot bodies and molecules. This band lies adjacent to the low-frequency or long-wavelength end of the visible spectrum.

(31) **(D).** Ultraviolet rays covers wavelength ranging about 4×10^{-7}m (400 nm) down to 6×10^{-10}m (0.6 nm). It is produced by special lamps and very hot bodies. The sun is an important source of ultraviolet light. But fortunately, most of it is absorbed in the ozone layer in the atmosphere at an altitude of about 40-50 km.

(32) **(B).** In the electromagnetic spectrum, X-ray region lies above the ultraviolet.

(33) **(D).** Microwaves are used to cook food. Microwave oven is a domestic application of these waves.

(34) **(B).** Due to its shorter wavelengths, ultraviolet radiation can be focussed in to very narrow beams for high precision application such as LASIK eye surgery.

(35) **(A).** In artificial satellite microwaves are used for communication.

(36) **(D).** The speed of all electromagnetic waves is same in vacuum.

(37) **(C).** Frequency of microwaves $\nu_m = 10^{11}$ Hz
Frequency of ultrasonic sound waves $\nu_u = 10^5$ Hz

$$\frac{\nu_m}{\nu_u} = \frac{10^{11}}{10^5} = 10^6$$

EXERCISE-2

(1) **(D).** $v = \frac{c}{\sqrt{\mu_r\varepsilon_r}} = \frac{3\times10^8}{\sqrt{1.3\times2.14}} = 1.8\times10^8\,\text{m/sec}$

(2) **(B).** $I = \frac{1}{2}\in_0 C E_0^{\,2}$

$$E_0 = \sqrt{\frac{2I}{\in_0 C}} = \sqrt{\frac{2\times500\times10^9\times36\pi}{\pi\times10^8\times3}}$$

$$E_0 = 2\sqrt{3}\times10^2\,\text{N/C}$$

(3) **(A).** $U_B = \frac{B_0^2}{4\mu_0}$; $\frac{E_0}{B_0} = C$

$$\therefore\ U_B = \frac{E_0^2\mu_0\in_0}{4\mu_0} = \frac{100\times8.84\times10^{-12}}{4}$$

$\therefore\ U_B = 2.21\times10^{-10}\ \text{J/m}^3$

(4) **(A).** The speed of electromagnetic waves and in a medium is given by $v = \frac{1}{\sqrt{(\mu\varepsilon)}}$

Where μ and ε are absolute permeability and absolute permittivity of the medium.
We know that, $\mu = \mu_0\mu_r$ and $\varepsilon = \varepsilon_0\varepsilon_r$.

$$v = \frac{1}{\sqrt{(\mu_0\mu_r.\varepsilon_0\varepsilon_r)}} = \frac{1}{\sqrt{(\mu_0\varepsilon_0)}}\times\frac{1}{\sqrt{(\mu_r\varepsilon_r)}}$$

$$v = \frac{c}{\sqrt{(\mu_r\varepsilon_r)}}\ ;\ \varepsilon_r = \frac{c^2}{v^2(\mu_r)} = \frac{(3\times10^8)^2}{(2\times10^8)^2\times1} = 2.25$$

(5) **(A).** $\lambda = \frac{c}{\nu} = \frac{3\times10^8}{8.2\times10^6} = 36.5$ m

(6) **(B).** $c = \frac{E}{B} \Rightarrow B = \frac{E}{c} = \frac{18}{3\times10^8} = 6\times10^{-8}$T

(7) **(A).** $I = \frac{1}{2}\varepsilon_0 C E_0^2$

$$E_0 = \sqrt{\frac{2I}{\varepsilon_0 C}} = \sqrt{\frac{2\times5\times10^{-16}\times36\pi\times10^9}{3\times10^8}}$$

$$= 0.61\times10^{-6}\ \text{V/m}$$

Also $E_0 = V_0/d$

$\Rightarrow V_0 = E_0 d = 0.61\times10^{-6}\times2 = 1.23\ \mu$V

(8) **(D).** The intensity of light at a point is given by

$$I = \langle S\rangle = \frac{1}{2\mu_0 c}\times E_0^2 \quad \therefore E_0 = \sqrt{2\mu_0 cI}$$

$$= \sqrt{2\times4\pi10^{-7}\times3\times10^8\times1.38\times10^3}$$
= 1.02 Kilovolt/meter

(9) **(A).** $\langle P_r\rangle = \frac{2}{3}\langle U\rangle$.....(1) ; $\langle P_a\rangle = \frac{\langle U\rangle}{3}$ .....(2)

From eqn. (1) and (2), $\frac{\langle P_r\rangle}{\langle P_a\rangle} = 2$

(10) **(D).** Maxwell's equations that electric and magnetic fields in an electromagnetic wave are perpendicular to each other and to the direction of propagation.

The electric field inside the plates of the capacitor is directed perpendicular to the plates.
The magnetic field due to displacement current is along the perimeter of a circle parallel to the capacitor plates. So, B and E are perpendicular in this case.

(11) **(A).** $\lambda_1 = \dfrac{c}{\nu_1} = \dfrac{3\times10^8}{7.5\times10^6} = 40\text{m}$

and $\lambda_2 = \dfrac{c}{\nu_2} = \dfrac{3\times10^8}{12\times10^6} = 25\text{m}$

(12) **(D).** As, $B = \dfrac{E}{c} = \dfrac{6.3}{3\times10^8} = 2.1\times10^{-8}\text{T}$

(13) **(A).** $P = \dfrac{I}{c} = \dfrac{0.5}{3\times10^8} = 0.166\times10^{-8}\,\text{Nm}^{-2}$

(14) **(B).** Given E = 13.2 keV

$$\lambda\ (\text{in Å}) = \frac{hc}{E\ (\text{in eV})} = \frac{12400}{13.2\times10^3} = 0.939\ \text{Å} = 1\text{Å}$$

(15) **(D).** $\lambda_{micro} > \lambda_{infrared} > \lambda_{ultraviolet} > \lambda_{gamma}$

(16) **(D).** The total current i is the sum of the condensation current denoted by i_c, and the displacement current denoted by $i_d\ (t) = \varepsilon_0\ (d\phi_E/dt)$.

So, we have, $i = i_e + i_d = i_c + \varepsilon_0 \dfrac{d\phi_\varepsilon}{dt}$

In explicit terms, this means that outside the capacitor plates, we have only conduction current $i_c = i$ and no displacement current, i.e. $i_d = 0$ and inside the capacitor, there is only displacement current, so that $i_d = i$.

EXERCISE-3

(1) **(A).**

(2) **(B).** β-rays are the beam of fast moving electrons.

(3) **(D).** Energy of γ-ray is maximum so wavelength is minimum.

(4) **(B).** Surface is reflecting so, change in momentum

$$= 2\times p = \frac{2E}{c}$$

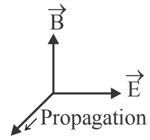
(5) **(C).** Refractive index, $\mu = \sqrt{\dfrac{\varepsilon}{\varepsilon_0}} = 2$

Speed and wavelength of wave will becomes half, the frequency remaining unchanged (frequency of a wave depends on the source as due to refraction, it is assumed that the energy is conserved. hν remains the same).

(6) **(B).** $U_{av} = \varepsilon_0 E_{rms}^2 = 4.58\times10^{-6}\,\text{J/m}^3$

$E_{rms}^2 = 4.58\times10^{-6}\,\text{J/m}^3$

(7) **(B).**



(8) **(B).** $\vec{E} = \vec{B}\times\vec{C}$

$|\vec{E}| = |\vec{B}|\times|\vec{C}| = 20\times10^{-9}\times3\times10^8 = 6\ \text{V/m}$

(9) **(B).** Infrared waves → To treat muscular strain
Radio waves → for broadcasting
X-rays → To detect fracture of bones
Ultraviolet rays → Absorbed by the ozone layer of the atmosphere.

(10) **(A).** Energy is equally divided between electric and magnetic field.

(11) **(D).** Energy of one quantum = hν
$\nu_C > \nu_A > \nu_B > \nu_D \Rightarrow D < B < A < C$

(12) **(A).** From wave equations : In air : $\omega = 2\pi\nu,\ k = \dfrac{2\pi\nu}{c}$

In medium, $\omega = kc,\ k' = 2k$

$$k = \frac{\omega}{c},\ k' = \frac{\omega}{c'} \Rightarrow \frac{\omega}{c'} = \frac{2\omega}{c} \Rightarrow c' = \frac{c}{2}$$

$$\frac{1}{\sqrt{\mu_0\mu_{r_2}\varepsilon_0\varepsilon_{r_2}}} = \frac{1}{\sqrt{\mu_0\mu_{r_1}\varepsilon_0\varepsilon_{r_1}}}\frac{1}{2}$$

Medium and air are non-magnetic

$$\mu_{r_1} = 1;\ \mu_{r_2} = 1;\ \frac{1}{\varepsilon_{r_2}} = \frac{1}{4\varepsilon_{r_1}} \Rightarrow \frac{\varepsilon_{r_1}}{\varepsilon_{r_2}} = \frac{1}{4}$$

(13) **(C).** $|B| = \dfrac{|E|}{C} = \dfrac{6.3}{3\times10^8} = 2.1\times10^{-8}\text{T}$

$\hat{E}\times\hat{B} = \hat{C}\,;\ \hat{j}\times\hat{B} = \hat{i},\ \hat{B} = \hat{k}$

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

(14) **(C).** The direction of propogation of an EM wave is direction of $\vec{E}\times\vec{B}$.

$\hat{i} = \hat{j}\times\hat{B} \Rightarrow \hat{B} = \hat{k}\,;\quad C = \dfrac{E}{B} \Rightarrow B = \dfrac{E}{C} = \dfrac{6}{3\times10^8}$

$B = 2\times10^{-8}$ T along z direction.

(15) **(A).** $\dfrac{E_0}{B_0} = C$ (speed of light in vacuum)

$E_0 = B_0 C = 3\times10^{-8}\times3\times10^8 = 9\ \text{N/C}$

(16) **(B).** $E = \vec{B}\times\vec{V}$

$= (5\times10^{-8}\ \hat{j})\times(3\times10^8\ \hat{k}) = 15\ \hat{i}\ \ \text{V/m}$

EXERCISE-4

(1) **(B).** We know $E = \frac{hc}{\lambda} \Rightarrow E \propto \frac{1}{\lambda}$

$E_m < E_v < E_x \qquad \therefore \lambda_m > \lambda_v > \lambda_x$

(2) **(D).** $v = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$ a standard formula

(3) **(B).** $E_y = E_0 \cos(\omega t - kx)$

$\omega = 2\pi f = 2\pi \times 10^6 \;\therefore\; f = 10^6$ Hz

$k = \frac{2\pi}{\lambda} = \pi \times 10^{-2}\, m^{-1}, \lambda = 200m$

(4) **(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.

(5) **(B).** The decreasing order of wavelength of infrared, microwave, ultraviolet and gamma rays is microwave, infrared, ultraviolet, gamma rays

(6) **(B).** $\vec{E} \times \vec{B}$ points in the direction of wave propagation.

(7) **(A).** $\omega = 6 \times 10^8$, $k = \frac{\omega}{v} = \frac{6 \times 10^8}{3 \times 10^8} = 2m^{-1}$

(8) **(B).** The frequency of the microwaves must match the resonant frequency of the water molecules.

(9) **(B).** Wavelengh of the ray, $\lambda = \frac{hc}{E} = 0.826$ Å

Since, $\lambda < 100$ Å. So it is X-ray

(10) **(D).** Accelerating charge produce electromagnetic wave.

(11) **(A).** $R = 100\,\Omega, X_c = 100\,\Omega$

$$I_{max} = \frac{E_0}{Z} = \frac{220\sqrt{2}}{\sqrt{100^2 + 100^2}} = 2.2 \text{ A}$$

(12) **(A).** $E_0 = CB_0$; $E_{rms} = \frac{E_0}{\sqrt{2}} \Rightarrow E_{rms}\sqrt{2} = CB_0$

$$B_0 = \frac{E_{rms}\sqrt{2}}{C} = \frac{6 \times \sqrt{2}}{3 \times 10^8} = 2.83 \times 10^{-8}\text{ T}$$

(13) **(B).** $\vec{E} \times \vec{B} = \vec{V}$; $(\vec{E}\hat{j}) \times (\vec{B}) = V\hat{i}$; So, $\vec{B} = B\,\hat{k}$

Direction of propagation is along +z direction.

(14) **(A).** Red has the longest wavelength among the given options.