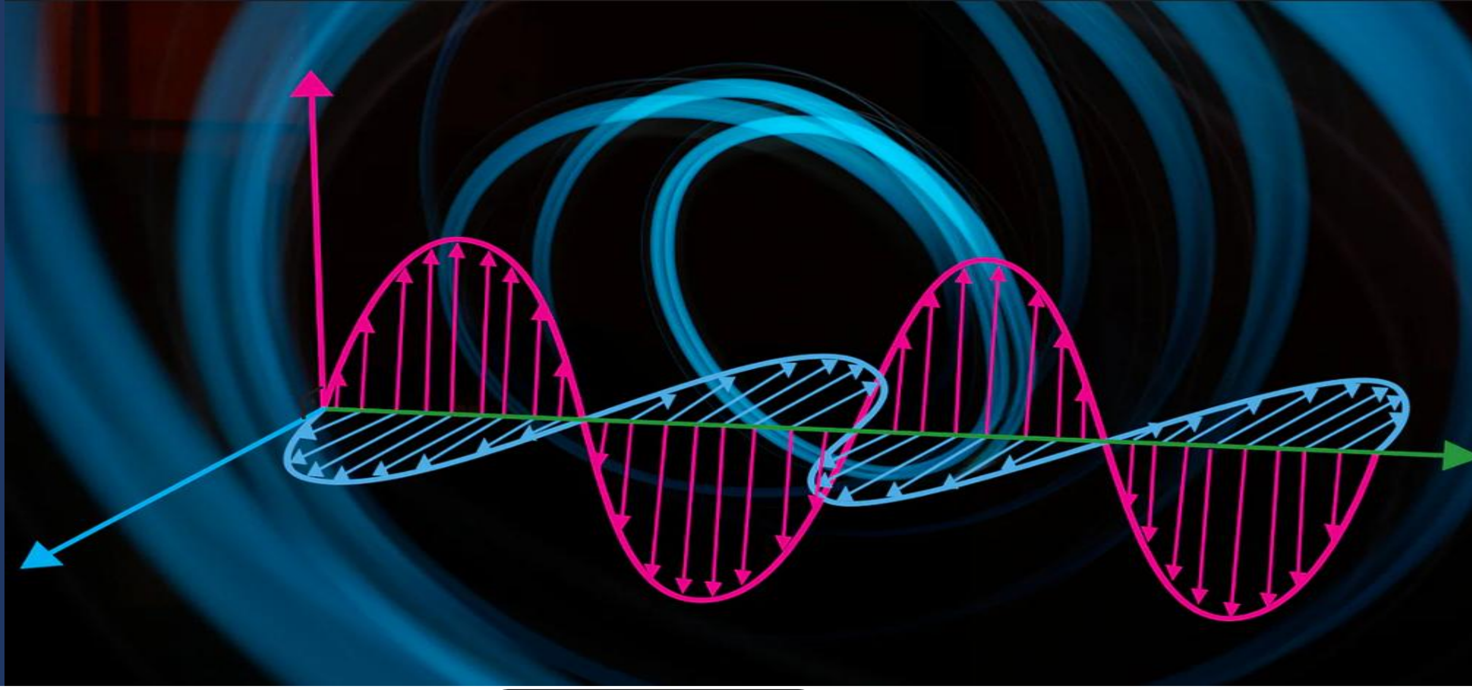
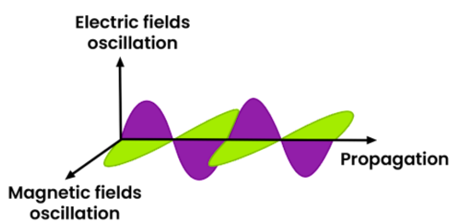


CHAPTER – 8

ELECTROMAGNETIC WAVES

A changing electric field produces a changing magnetic field and vice versa which gives rise to a transverse wave known as electromagnetic waves. The time varying electric field and magnetic field mutually perpendicular to each other also perpendicular to the direction of propagation.
Thus, the electromagnetic waves consist of sinusoidally time varying electric and magnetic field acting at right angles to each other as well as at right angles to the direction of propagation.



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 6m.
Seven year later, J.C. Bose became successful in producing electromagnetic waves of wavelength in the range 5mmto25mm.

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 up to several kilometers.
The antenna and the earth wires from the two plates of a capacitor which radiates radio frequency waves. These waves could be received at a large distance by making use of an antenna earth system as detector.
Using these arrangements, in 1899 Marconi first established wireless communication across the English Channel i.e., across a distance of about 50 km.

Displacement current

When a capacitor is allowed to charge in an electric circuit, the current flows through connecting wires. As capacitor charges, charge accumulates on the two plates of capacitor and as a result, a changing electric field is produced across between the two plates of the capacitor.
According to maxwell changing electric field intensity is equivalent to a current through capacitor that current is known as displacement current (I_d). If + q and – q be the charge on the left and right plates of the capacitor respectively at any instant if σ be the surface charge density of plate of capacitor the electric field between the plate is given by

$$E=\frac{\sigma}{\epsilon_0}=\frac{q}{\epsilon_0 A}$$

charge on the plates of the capacitor increased by dq in time dt then dq = I dt

change in electric field is $dE=\frac{dq}{\epsilon_0 A}=\frac{Idt}{\epsilon_0 A}\Rightarrow\frac{dE}{dt}=\frac{1}{\epsilon_0 A}I$

$$=\epsilon_0 A\frac{dE}{dt}=\epsilon_0\frac{d}{dt}(EA)=\epsilon_0\frac{d\phi_E}{dt}\qquad(\because \phi_E = EA)$$

$$\boxed{I_d=\epsilon_0\frac{d\phi_E}{dt}}$$

The conduction cogent is the current due to the flow of charges in a conductor and is denoted as Ic and displacement current is the current due to changing electric field between the plate of the capacitor and denoted as Id so the total current I is sum of I_c and I_d i.e. $I = I_c + I_d$

Ampere's circuital law can be written as

$$\oint \vec{B}.\vec{d\ell} = \mu_0(I_c + I_d)$$

$$\Rightarrow \oint \vec{B}.\vec{d\ell} = \mu_0(I_c + \epsilon_0 \frac{d\phi_E}{dt})$$

Q. 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. Then determine the conduction current through the connecting wires, and the displacement current through the plates of the capacitor.

Sol. Here, C = 20 µF

The rate of change of potential = 3 V/s

The charge on the capacitor, $Q = CV$

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

Displacement current is equal to the conduction current.

Q. A 100 Ω resistance and a capacitor of 100 Ω reactance is connected in series across a 220 V source. When the capacitor is 50% charged, then find the peak value of the displacement current.

Sol. 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

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

Maxwell's equation

There are four Maxwell's equations are given below

(1) Gauss law in electrostatics:

$\oint \vec{E}.\vec{ds} = \frac{q}{\epsilon_0}$ ...eq(i)

(2) Gauss law in magnetism:

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

(3) Faraday's law of electromagnetic induction:

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

(4) Maxwell- Ampere's circuital law:

$\oint \vec{B}.\vec{d\ell} = \mu_0\left[I_c + \epsilon_0 \frac{d\phi_E}{dt}\right]$ ...eq(iv)

Electromagnetic waves

Sources of electromagnetic waves

Let's consider a charge oscillating at a particular frequency. Remember, an oscillating charge is an example of an accelerating charge. This charge produces an oscillating electric field which results in an oscillating magnetic field which in turn is the source of an electric field and so on. In simple words, the oscillating electric and magnetic fields regenerate each other propagating the wave through space. The frequency of the electromagnetic wave equals that of the oscillation of the charge. The energy required to propagate the wave through space comes at the expense of the accelerated charge. The first logical thought is that it will be easy to test the prediction that light is an electromagnetic wave. We merely need to set up an AC circuit in which the current oscillates at the frequency of visible light, like the yellow light. However, that is simply not possible. Here's why: The frequency of yellow light is around 6 x 10^{14} The frequency available with most modern electronic circuits is around 1011 Hence, the experimental demonstration of electromagnetic waves can happen only in the low-frequency region (radio wave region). This was done by Hertz in an experiment in 1887.

Properties of electromagnetic waves

The electric and magnetic fields satisfy the following wave equations, which can be obtained from Maxwell's third and fourth equations.

$\frac{\partial^2 E}{\partial x^2} = \mu_0\varepsilon_0\frac{\partial^2 E}{\partial t^2}$ and $\frac{\partial^2 B}{\partial x^2} = \mu_0\varepsilon_0\frac{\partial^2 B}{\partial t^2}$

Electromagnetic waves travel through vacuum with the speed of light c, were

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

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 instantaneous magnitudes of $\vec{E}$ and $\vec{B}$ in an electromagnetic wave are related by the expression.

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

Electromagnetic waves carry energy. The rate of flow of energy crossing a unit area is described by the Poynting vector $\vec{S}$. were

$\vec{S} = \frac{1}{\mu_0}\vec{E} \times \vec{B}$

Electromagnetic waves carry momentum and hence can exert pressure (P) on surfaces, which is known as radiation pressure. For an electromagnetic wave with Poynting vector $\vec{S}$, incident upon a perfectly absorbing surface $P = \frac{S}{c}$ and if incident upon a perfectly reflecting surface $P = \frac{2S}{c}$

The electric and magnetic fields of a sinusoidal plane electromagnetic wave propagating in the positive x-direction can also be written as

E = E_m sin (kx – ωt)
and B = B_m sin (kx – ωt)
where ω is the angular frequency of the wave and k is wave number which are given by

ω = 2πf and $k = \frac{2\pi}{\lambda}$

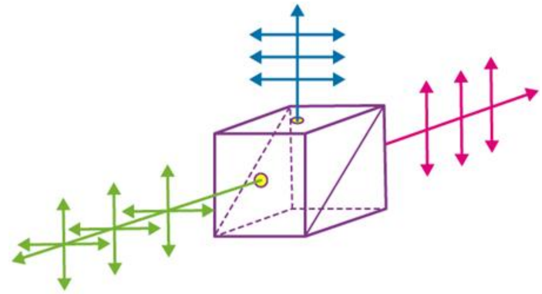
The intensity of a sinusoidal plane electro-magnetic wave is defined as the average value of Poynting vector taken over one cycle.

$S_{av} = \frac{E_m B_m}{2\mu_0} = \frac{E_m^2}{2\mu_0 c} = \frac{c}{2\mu_0} B_m^2$

The fundamental sources of electromagnetic waves are accelerating electric charges. For examples radio waves emitted by an antenna arises from the continuous 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.

Transverse nature of electromagnetic waves

Maxwell proved that both the electric and magnetic fields are perpendicular to each other in the direction of wave propagation. He considered an electromagnetic wave propagating along the positive x-axis. When a rectangular parallelepiped was placed parallel to the three-co-ordinate axis, the electric and magnetic fields propagate sinusoidal with the x-axis and are independent of the y and z-axis. The figure shows a rectangular parallelepiped in a positive direction.



The rectangular parallelepiped does not enclose any charge thus the total electric flux across it must be zero. This law is called gauss' law, i.e.

$\oint \vec{E}.\vec{d}S = 0$

Have you ever anchored one end of a rope and held the other end in your hand? You can create a transverse wave by moving your hands in a different direction. The electric field remains the same at different points on the x-axis; this proves that the electric field is static in nature. It is known that static fields can propagate as a wave, hence EX = 0. The component of the electric field along the direction of propagation is zero as the electric field is perpendicular to the direction of wave propagation. This also proves for a magnetic field, as the magnetic field is also perpendicular to the direction of wave propagation. This proves the transverse nature of electromagnetic waves to the direction of wave propagation.

Q. 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. Then determine the energy received by the surface during time span of 1 minute.

Sol. Energy received in 1 minute = Intensity × Area × Time

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

Q. In an electromagnetic wave in free space the root mean square value of the electric field is E_{rms} = 6 V m^{-1}. Then find peak value of the magnetic field.

Sol. Given: $E_{\mathrm{rms}} = 6\ \mathrm{V\ m^{-1}}$

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

$B_{\mathrm{rms}} = \frac{6}{3\times10^8} = 2 \times 10^{-8}$ T

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

where B_0 is the peak value of magnetic field.

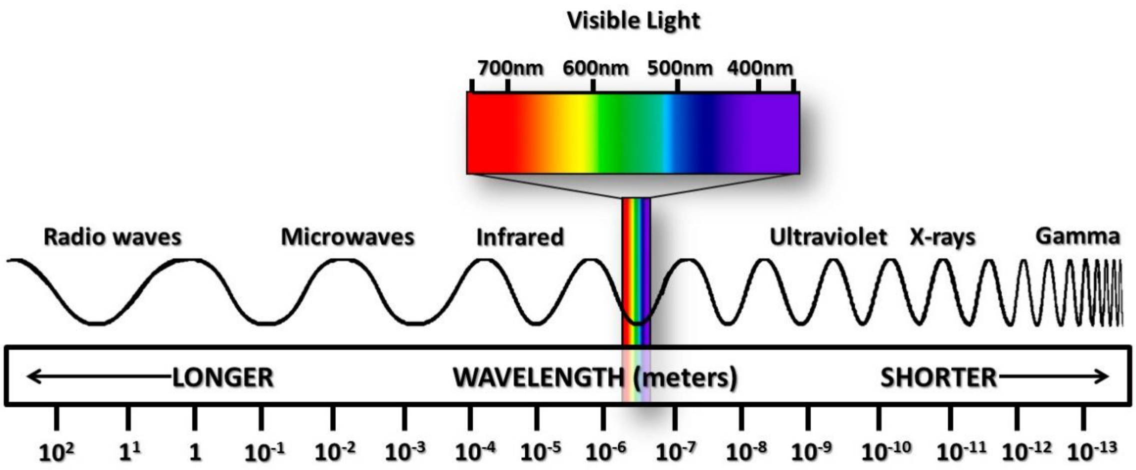
$\therefore\ B_0 = B_{\mathrm{rms}}\sqrt{2} = 2 \times 10^{-8} \times \sqrt{2}T$

$B_0 \approx 2.83 \times 10^{-8}$ T

Electromagnetic spectrum

The electromagnetic spectrum is a range of frequencies, wavelengths and photon energies covering frequencies from below 1 hertz to above 1025 Hz corresponding to wavelengths which are a few kilometers to a fraction of the size of an atomic nucleus in the spectrum of electromagnetic waves. Generally, in vacuum electromagnetic waves tend to travel at speeds which is similar to that of light. However, they do so at a wide range of wavelengths, frequencies, and photon energies. The electromagnetic spectrum consists of a span of all electromagnetic radiation which further contains many subranges which are commonly referred to as portions. These can be further classified as infra-red radiation, visible light or ultraviolet radiation.

Electromagnetic spectrum



Radio waves: A radio basically captures radio waves that are transmitted by radio stations. Radio waves can also be emitted by gases and stars in space. Radio waves are mainly used for TV/mobile communication. They are generally in the frequency range from 500 kHz to about 1000 MHz. The AM (amplitude modulated) band is from 530 kHz to 1710 kHz. Higher frequencies upto 54 MHz are used for short wave bands. TV waves range from 54 MHz to 890 MHz. The FM (frequency modulated) radio band extends from 88 MHz to 108 MHz

Microwave: Microwaves (short-wavelength radio waves), with frequencies in the gigahertz (GHz) range, are produced by special vacuum tubes (called klystrons, magnetrons and Gunn diodes). Due to their short wavelengths, they are suitable for the radar systems used in aircraft navigation. Radar also provides the basis for the speed guns used to time fast balls, tennis serves, and automobiles. This type of radiation is found in microwaves and helps in cooking at home/office. It is also used by astronomers to determine and understand the structure of nearby galaxies and stars.

Infrared Waves: Infrared waves are produced by hot bodies and molecules. This band lies adjacent to the low-frequency or long-wave length end of the visible spectrum. Infrared waves are sometimes referred to as heat waves. This is because water molecules present in most materials readily absorb infrared waves (many other molecules, for example, CO_2, NH_3, also absorb infrared waves). After absorption, their thermal motion increases, that is, they heat up and heat their surroundings. It is used widely in night vision goggles. These devices can read and capture the infrared light emitted by our skin and objects with heat. In space, infrared light helps to map the interstellar dust.

X-ray: Beyond the UV region of the electromagnetic spectrum lies the X-ray region. We are familiar with X-rays because of its medical applications. It covers wavelengths from about 10^{-8} m (10 nm) down to 10^{-13} m (10–4 nm). X-rays can be used in many instances. For example, a doctor can use an x-ray machine to take an image of our bone or teeth. Airport security personnel use it to see through and check bags. X-rays are also given out by hot gases in the universe.

Gamma-ray: They lie in the upper frequency range of the electromagnetic spectrum and have wavelengths of from about 10^{-10}m to less than 10^{-14}m. It has a wide application in the medical field. Gamma-ray imaging is used to see inside our bodies. Interestingly, the universe is the biggest gamma-ray generator of all.

Ultraviolet rays: It covers wavelengths ranging from about 4×10^{-7} m (400 nm) down to 6×10^{-10}m (0.6 nm). Ultraviolet (UV) radiation 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. UV light in large quantities has harmful effects on humans. Exposure to UV radiation induces the production of more melanin, causing tanning of the skin. UV radiation is absorbed by ordinary glass. Hence, one cannot get tanned or sunburn through glass windows. Hot materials that are in space also emit UV radiations.

Visible light: It runs from about 4×10^{14} Hz to about 7×10^{14} Hz or a wavelength range of about 700 – 400 nm. Visible light emitted or reflected from objects around us provides us information about the world. Visible light can be detected by our eyes. Light bulbs, stars, etc. emit visible light.

SUMMARY

- **Displacement Current:**
  It is due to time-varying electric field is,
  $i_d = \varepsilon_0 \frac{d\phi_E}{dt}$
  Displacement current acts as a source of magnetic field in exactly the same way as conduction current.
- **Electromagnetic Waves:**
  (a) Electromagnetic waves are produced only by charges that are accelerating, since acceleration is absolute, and not a relative phenomenon.
  (b) An electric charge oscillating harmonically with frequency υ, produces electromagnetic waves of the same frequency υ.
  (c) An electric dipole is a basic source of electromagnetic waves.
  (d) Electromagnetic waves with wavelength of the order of a few metres were first produced and detected in the laboratory by Hertz in 1887. He thus verified a basic prediction of Maxwell's equations.
- **Oscillation of Electric and Magnetic Fields:**
  These oscillate sinusoidally in space and time in an electromagnetic wave. The oscillating electric and magnetic fields, E and B are perpendicular to each other and to the direction of propagation of the electromagnetic wave.
- For a wave of frequency υ, wavelength λ, propagating along *z*-direction,
  $E = E_X(t) = E_0 \sin(kz - \omega t)$
  $= E_0 \sin\left[2\pi\left(\frac{z}{\lambda} - \upsilon t\right)\right] = E_0 \sin\left[2\pi\left(\frac{z}{\lambda} - \frac{t}{T}\right)\right]$
  $B = B_Y(t) = B_0 \sin(kz - \omega t)$
  $= B_0 \sin\left[2\pi\left(\frac{z}{\lambda} - \upsilon t\right)\right] = B_0 \sin\left[2\pi\left(\frac{z}{\lambda} - \frac{t}{T}\right)\right]$
  They are related by $\frac{E_0}{B_0} = c$
- **Relation between μ_0 and 0 ε_0:**
  The speed *c* of electromagnetic wave in vacuum is related to μ_0 and ε_0 (the free space permeability and permittivity constants) as
  $C = 1/\sqrt{\mu_0 \varepsilon_0}$
- The value of *c* equals the speed of light obtained from optical measurements. Light is an electromagnetic wave; *c* is, therefore, also the speed of light. Electromagnetic waves other than light also have the same velocity c in free space.
- **Speed of Light:**
  The speed of light, or of electromagnetic waves in a material medium is
  $v = 1\sqrt{\mu\varepsilon}$
  Where μ is the permeability of the medium and ε its permittivity
- Electromagnetic waves carry energy as they travel through space and this energy is shared equally by the electric and magnetic fields.
- **Energy Per Unit Volume:**
  If in a region of space in which there exist electric and magnetic fields $\vec{E}$ and $\vec{B}$, there exists Energy Density (Energy per unit volume) associated with these fields is,
  $U = \frac{\omega_0}{2}\vec{E}^2 + \frac{1}{2\mu_0}\vec{B}^2$
  where we are assuming that the concerned space consists of vacuum only.
- Electromagnetic waves transport momentum as well. When these waves strike a surface, a pressure is exerted on the surface.
- If total energy transferred to a surface in time *t* is *U*, total momentum delivered to this surface is *p = U/c*.
- **Electromagnetic Spectrum:**
  The spectrum of electromagnetic waves stretches, in principle, over an infinite range of wavelengths.
  The classification of electromagnetic waves according to frequency is the electromagnetic spectrum.
  There is no sharp division between one kind of wave and the next.
- The classification has more to do with the way these waves are produced and detected.
- **Different Regions of Spectrum:**
  Different regions are known by different names; γ -rays, X-rays, ultraviolet rays, visible rays, infrared rays, microwaves and radio waves in order of increasing wavelength from 10^{-2} Å or 10^{-12} m to 10^{6} m.

(a) Radio Waves:
- ✓ These are produced by accelerated motion of charges in wires.
- ✓ These are used in radio and television communication systems.
- ✓ These are generally in the frequency range from 500 kHz to about 1000 MHz.

(b) Microwaves:
- ✓ These are short wavelength radio waves with frequencies in the gigahertz range.
- ✓ Due to their short wavelengths, they are suitable for radar systems used in aircraft navigation.
- ✓ Microwave ovens use them for cooking.

(c) Infrared Waves:
- ✓ These are produced by hot bodies and molecules.
- ✓ They lie in the low frequency or long wavelength end of the visible spectrum.

(d) Visible Light:
- ✓ The spectrum runs from about 4 x 10^{14} Hz to about 7 x 10^{14} Hz.
- ✓ Our eyes are sensitive to this range of wavelengths.

(e) Ultraviolet light:
- ✓ It covers wavelengths ranging from 400 nm to 0.6 nm.
- ✓ The sun is an important source of UV rays.

(f) X-rays:
- ✓ These cover the range 10 nm to about 10^{-4} nm.

(g) Gamma Rays:
- ✓ These lie in the upper frequency range of the spectrum, and have wavelengths in the range 10^{-10} m to 10^{-14} m.

MIND MAP

Electromagnetic Waves

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

Conduction Current

The current due to flow of charge is often called $i_c = \frac{d\theta}{dt}$

Displacement Current

If there exists an electric current as well as a changing electric field, results magnetic field & cause displacement current

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

Contribution

In 1886 Henrich Hertz became the first person to transmit and received controlled radio waves

Maxwell's Equation

Gauss's Law (electricity)

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

Gauss's Law (magnetism)

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

Faraday's Law

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

Ampere's Law

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

Electromagnetic spectrum

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

Energy density

- $U = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\frac{B^2}{\mu_0}$
  = energy per unit volume
- U_{av} over a long time
  $= \frac{1}{4}\varepsilon_0 E_0^2 + \frac{1}{4}\frac{B_0}{\mu_0}$
  $= \frac{1}{2}\varepsilon_0 E_0^2$ [as $c = B/E_0$ & $\mu_0\varepsilon_0 = \frac{1}{c^2}$]
  $= \frac{1}{2}\frac{B_0^2}{\mu_0}$

Characteristics of Electromagnetic waves

1- • Do not need any material medium for propagation

2- • Travels with speed (v) = $\frac{1}{\sqrt{\mu_0\varepsilon_0}}$

3- • Produced by accelerated charge

4- • Transverse in nature

5- • Oscillating electric & magnetic fields are in phase and their ratio is constant (C) = E_0/B_0

QUESTIONS FOR PRACTICE

MCQ

Q1. 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

(a) $\vec{X} \parallel \vec{B}$ and $\vec{k} \parallel \vec{B} \times \vec{E}$ (b) $\vec{X} \parallel \vec{E}$ and $\vec{k} \parallel \vec{E} \times \vec{B}$

(c) $\vec{X} \parallel \vec{B}$ and $\vec{k} \parallel \vec{E} \times \vec{B}$ (d) $\vec{X} \parallel \vec{E}$ and $\vec{k} \parallel \vec{B} \times \vec{E}$

Q2. 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) $1 : c^2$

Q3. 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

(a) $4.58 \times 10^{-6}\ J/m^3$ (b) $6.37 \times 10^{-9}\ J/m^3$

(c) $81.35 \times 10^{-12}\ J/m^3$ (d) $3.3 \times 10^{-3}\ J/m^3$

Q4. Which of the following electromagnetic radiations have the longest wavelength?

(a) X-rays (b) γ-rays

(c) Microwaves (d) Radio waves

Q5. In order to establish an instantaneous displacement current of 1 mA in the space between the plates of $2\mu F$ parallel plate capacitor, the potential difference need to apply is

(a) $100\ Vs^{-1}$ (b) $200\ Vs^{-1}$

(c) $300\ Vs^{-1}$ (d) $500\ Vs^{-1}$

Q6. During the propagation of electromagnetic waves in a medium:

(a) Electric energy density is double of the magnetic energy density.

(b) Electric energy density is half of the magnetic energy density.

(c) Electric energy density is equal to the magnetic energy density.

(d) Both electric and magnetic energy densities are zero.

Q7. An electromagnetic wave with frequency ω and wavelength λ travels in the + y direction. Its magnetic field is along + x – axis. The vector equation for the associated electric field (of amplitude E_0) is

(a) $\vec{E} = -E_0 \cos\left(\omega t + \frac{2\pi}{\lambda} y\right) \hat{x}$

(b) $\vec{E} = E_0 \cos\left(\omega t - \frac{2\pi}{\lambda} y\right) \hat{x}$

(c) $\vec{E} = E_0 \cos\left(\omega t - \frac{2\pi}{\lambda} y\right) \hat{z}$

(d) $\vec{E} = -E_0 \cos\left(\omega t + \frac{2\pi}{\lambda} y\right) \hat{z}$

Q8. An electromagnetic wave of frequency v = 3.0 MHz passes from vacuum into a dielectric medium with permittivity $\in = 4.0$. Then

(a) wavelength is halved and frequency remains unchanged

(b) wavelength is doubled and frequency becomes half

(c) wavelength is doubled and the frequency remains unchanged

(d) wavelength and frequency both remain unchanged.

Q9. The average electric field of electromagnetic waves in certain region of free space is $9 \times 10^{-4}\ NC^{-1}$. Then the average magnetic field in the same region is of the order of

(a) $27 \times 10^{-4} T$ (b) 3×10^{-12}T

(c) $\left(\frac{1}{3}\right) \times 10^{-12}\ T$ (d) $3 \times 10^{12}\ T$

Q10. Biological importance of ozone layer is

(a) it stops ultraviolet rays

(b) ozone layer reduces greenhouse effect

(c) ozone layer reflects radio waves

(d) ozone layer controls O_2/H_2 ratio in atmosphere.

Q11. The electric and the magnetic field associated with an E.M. wave, propagating along the + z-axis, can be represented by

(a) $[\vec{E} = E_0 \hat{\imath}, \vec{B} = B_0\ \hat{\jmath}]$ (b) $[\vec{E} = E_0 \vec{k}, \vec{B} = B_0\ \hat{\imath}]$

(c) $[\vec{E} = E_0 \hat{\jmath}, \vec{B} = B_0\ \hat{\imath}]$ (d) $[\vec{E} = E_0 \hat{\jmath}, \vec{B} = B_0\ \hat{k}]$

Q12. The energy of electromagnetic wave in vacuum is given by the relation

(a) $\frac{E^2}{2\varepsilon_{0-}} + \frac{B^2}{2\mu_0}$ (b) $\frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\mu_0 B^2$

(c) $\frac{E^2+B^2}{c}$ (d) $\frac{1}{2}\varepsilon_0 E^2 + \frac{B^2}{2\mu_0}$

Q13. 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

Q14. A plane electromagnetic wave is incident on a plane surface of area A, normally and is perfectly reflected. If energy E on the surface is ($c = speed\ of\ light$)

(a) zero (b) E/Atc

(c) $2E/Atc$ (d) E/c

Q15. An electromagnetic wave travels along z-axis. Which of the following pairs of space and time varying fields would generate such a wave?

(a) E_x, B_y (b) E_y, B_x

(c) E_2, B_x (d) E_y, B_z

Q16. The magnetic field in a travelling electromagnetic wave has a peak value of 20 nT. The peak value of electric field strength is:
(a) 3 V/m
(b) $6V/m$
(c) $9V/m$
(d) $12V/m$

Q17. Microwave oven acts on the principle of :
(a) giving translational energy to water molecules
(b) giving translational energy to water molecules
(c) giving vibrational energy to water molecules
(d) transferring electrons from lower to higher energy levels in water molecule

Q18. Displacement current is
(a) continuous when electric field is changing in the circuit
(b) continuous when magnetic field is changing in the circuit
(c) continuous in both types of fields
(d) continuous through wires and resistance only

Q19. A radiation of energy 'E' falls normally on a perfectly reflecting surface. The momentum transferred to the surface is (C = Velocity of light)
(a) $\frac{2E}{C}$ (b) $\frac{2E}{C^2}$
(c) $\frac{E}{C^2}$ (d) $\frac{E}{C}$

Q20. Photons of an electromagnetic radiation has an energy 11 keV each. To which region of electromagnetic spectrum does it belong?
(a) X-ray region (b) Ultra violet region
(c) Infrared region (d) Visible region

Q21. A plane electromagnetic wave travels in free space along x-axis. At a particular point in space, the electric field along x-axis. At a particular point in space, the electric field along y-axis is 9.3 V m^{-1}. The magnetic induction (b) along z-axis is
(a) $3.1 \times 10^{-8} T$ (b) $3 \times 10^{-5}\ T$
(c) $3 \times 10^{-6}\ T$ (d) $9.3 \times 10^{-6}\ T$

Q22. The ratio of amplitude of magnetic field to the amplitude of electric 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

Q23. A plane electromagnetic wave is incident on a material surface. If the wave delivers momentum p and energy E, then
(a) $p = 0, E = 0$ (b) $p \neq 0, E \neq 0$
(c) $p \neq 0, E = 0$ (d) p = 0, E $\neq$ 0

Q24. An em wave is propagating in a medium with a velocity $\vec{v} = v\hat{\imath}$. 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

Q25. 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}

ASSERTION AND REASONING

Directions: These questions consist of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following four responses.
(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.
(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.
(c) If the Assertion is correct but Reason is incorrect.
(d) If both the Assertion and Reason are incorrect.

Q1. Assertion (A): Short wave band is used for transmission of radio waves to large distances.
Reason (R): Short waves are reflected by earth's ionosphere.

Q2. Assertion (A): Light can travel in vacuum but sound cannot.
Reason (R): Light is an electromagnetic wave but sound is a mechanical wave.

Q3. Assertion (A): Light can travel in vacuum but sound cannot do so.
Reason (R): Light is an electromagnetic wave and sound is a mechanical wave.

Q4. Assertion (A): Gamma rays are more energetic than X-rays.
Reason (R): Gamma rays are of nuclear origin but X-rays are produced due to sudden deceleration of high energy electron while falling on a metal of high atomic number

Q5. Assertion (A): The speed of electromagnetic waves in free space is maximum for gamma rays and minimum for radio waves.
Reason (R): For waves with same wavelengths this just means that the speed will be equal to *c*.

VERY SHORT ANSWER QUESTIONS

Q1. The charging current for a capacitor is 0.25 A. What is the displacement current across its plates?

Q2. What are the directions of electric and magnetic field vectors relative to each other and relative to the direction of propagation of electromagnetic waves?

Q3. Which part of the electromagnetic spectrum is used in operating a RADAR?

Q4. Name the electromagnetic waves, which (i) maintain the Earth's warmth and (ii) are used in aircraft navigation.

Q5. Why are infra-red radiations referred to as heat waves? Name the radiations which are next to these radiations in the electromagnetic spectrum having (i) shorter wavelength (ii) longer wavelength.

SHORT ANSWER QUESTIONS

Q1. State two properties of electromagnetic waves. How can we show that EM waves carry momentum?

Q2. How does Ampere-Maxwell law explain the flow of current through a capacitor when it is being charged by a battery? Write the expression for the displacement current in terms of the rate of change of electric flux.

Q3. (a) How does oscillating charge produce electromagnetic waves?
(b) Sketch a schematic diagram depicting oscillating electric and magnetic fields of an em wave propagating along + z-direction.

Q4. Explain briefly how electromagnetic waves are produced by an oscillating charge. How is the frequency of EM waves produced related to that of the oscillating charge?

Q5. (a) Why are infra-red waves often called heat waves? Explain. (b) What do you understand by the statement, ''Electromagnetic waves transport momentum''?

NUMERICAL TYPE QUESTIONS

Q1. A point source of electromagnetic radiation has an average power output of 800W. Then find the maximum value of electric field at a distance 3.5 m from the source.

Q2. Radio receiver receives a message at 300m band, If the available inductance is 1 mH, then calculate required capacitance.

Q3. In a plane electromagnetic wave, the electric field oscillates sinusoidally at a frequency of
2.0×10^{10} Hz and amplitude 48 V /m,
(a) What is the wavelength of the wave?
(b) What is the amplitude of the oscillating magnetic field?
(c) Find the total average energy density of the electromagnetic field of the wave,

Q4. In an electromagnetic wave, the amplitude f electric field is I V /m. The frequency of wave is 5×10^{14} Hz. The wave is propagating along z-axis. Then find the average energy density of electric field, in Joule/m^3.

Q5. A plane light wave in the visible region is moving along the Z-direction. The frequency of the wave is 0.5×10^{15} Hz and the electric field at any point is varying sinusoidally with time with an amplitude of 1 V /m. Calculate the energy densities of the electric and magnetic fields.

Q6. In a plane electromagnetic wave, the electric field oscillates with a frequency of $2 \times 10^{10}\ \mathrm{s}^{-1}$ and an amplitude of $40\mathrm{Vm}^{-1}$.
(i) What is the wavelength of the wave?
(ii) What is the energy density due to electric field?

Q7. In order to establish an instantaneous displacement current of 1 mA in the space between the plates of 2PF parallel plate capacitor, then determine the potential difference which is need to apply

Q8. The electric field of an electromagnetic wave travelling through vacuum is given by the equation $E = E_0 \sin(kx - \omega t)$. Then find the quantity that is independent of wavelength.

Q9. An electromagnetic wave of frequency X = 3 MHz passes from vacuum into a dielectric medium with permittivity $\varepsilon = 4$. Then what will happened with wavelength?

Q10. The magnetic field in a travelling electromagnetic wave has a peak value of 20 nT. Then determine the peak value of electric field strength.

HOMEWORK EXERCISE

MCQ

Q1. 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

Q2. 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

Q3. 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

Q4. 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) $\sqrt{\frac{\varepsilon_0\mu_0}{\varepsilon\mu}}$ (b) $\sqrt{\frac{\varepsilon\mu}{\varepsilon_0\mu_0}}$
(c) $\sqrt{\frac{\varepsilon_0\mu}{\varepsilon\mu_0}}$ (d) $\sqrt{\frac{\varepsilon}{\varepsilon_0}}$

Q5. 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.

Q6. Which of the following electromagnetic radiations have the smaller wavelength?
(a) X-rays (b) γ-rays
(c) UV waves (d) microwaves

Q7. The structure of solids is investigated by using
(a) cosmic rays (b) X-rays
(c) γ-rays (d) infra-red radiations

Q8. What is the cause of Greenhouse effect?
(a) Infra-red rays (b) Ultra violet rays
(c) X-rays (d) Radio waves

Q9. 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) $\lambda_v > \lambda_m > \lambda_x$

Q10. The velocity of electromagnetic radiation in a medium of permittivity ε_0 and permeability μ_0 is given by
(a) $\frac{1}{\sqrt{\mu_0\varepsilon_0}}$ (b) $\sqrt{\frac{\mu_0}{\varepsilon_0}}$
(c) $\sqrt{\frac{\varepsilon_0}{\mu_0}}$ (d) $\sqrt{\mu_0\varepsilon_0}$

VERY SHORT ANSWER QUESTIONS

Directions: These questions consist of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following four responses.
(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.
(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.
(c) If the Assertion is correct but Reason is incorrect.
(d) If both the Assertion and Reason are incorrect.

Q1. Assertion (A): Electromagnetic waves are transverse.
Reason (R): The electric and magnetic fields of an electromagnetic wave are perpendicular to each other and also perpendicular to the direction of wave propagation

Q2. Assertion (A): Dipole oscillations produce electromagnetic waves.
Reason (R): Accelerated charge produces electromagnetic waves.

Q3. Assertion (A): Microwaves are better carriers of signals than optical waves.
Reason (R): Microwaves move faster than optical waves.

Q4. Assertion (A): If a beam of polarized light passes through a polaroid with polarization angle θ to the axis of polarization of the sheet, the intensity of transmitted light is $I = I_0 \cos^2\theta$.
Reason (R): In the situation described above, electric field amplitude is given by $E = E_0 \cos\theta$.

Q5. Assertion (A): In an electromagnetic wave electric and magnetic field vectors are mutually perpendicular and have a phase of $\frac{\pi}{2}$.
Reason (R): Phase difference refers to time difference. There is a time difference between the peaks of electric and magnetic oscillations in EM waves.

VERY SHORT ANSWER QUESTIONS

Q1. From the following, identify the electromagnetic waves having the
(i) Maximum (ii) Minimum frequency
(a) Radio waves (b) Gamma-rays
(c) Visible light (d) Microwaves
(e) Ultraviolet rays, and (f) Infrared rays

Q2. Why is the orientation of the portable radio with respect to broadcasting station important?

Q3. How are infrared waves produced?

Q4. A variable frequency ac source is connected to a capacitor. How will the displacement current change with decrease in frequency?

Q5. Welders wear special goggles or face masks with glass windows to protect their eyes from electromagnetic radiations. Name the radiations and write the range of their frequency.

SHORT ANSWER QUESTIONS

Q1. Name the parts of the electromagnetic spectrum which is
(i) suitable for radar systems used in aircraft navigation.
(ii) used to treat muscular strain.
(iii) used as a diagnostic tool in medicine. Write in brief, how these waves can be produced.

Q2. Answer the following questions:
(a) Name the EM waves which are produced during radioactive decay of a nucleus. Write their frequency range.
(b) Welders wear special glass goggles while working. Why? Explain.
(c) Why are infrared waves often called as heat waves? Give their one application.

Q3. (a) How are electromagnetic waves produced by oscillating charges?
(b) State clearly how a microwave oven works to heat up a food item containing water molecules.
(c) Why are microwaves found useful for the radar systems in aircraft navigation?

NUMERICAL TYPE QUESTIONS

Q1. If a source is transmitting electromagnetic wave of frequency 8.2 × 106 Hz, then determine the wavelength of the electromagnetic waves transmitted from the source.

Q2. In a plane electromagnetic wave propagating in space has an electric field of amplitude 9 × 103 V/m, then find the amplitude of the magnetic field.

Q3. The electric field associated with an electromagnetic wave in vacuum is given by $[E = \hat{\imath} 40 \cos(kz - 6 \times 10^8 t)]$; where E, z and t are in volt/m, meter and seconds respectively. Then find the value of wave vector k.

Q4. 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, then determine the average force exerted on the surface.

Q5. A plane light wave in the visible region is moving along the Z-direction. The frequency of the wave is 0.5×10^{15} Hz and the electric field at any point is varying sinusoidally with time with an amplitude of 1 V /m. Calculate the energy densities of the electric and magnetic fields.

PRACTICE EXERCISE SOLUTIONS

MCQ

S1. **(b)** $\therefore$ The E.M. Wave are transverse in nature i.e., $= \frac{\vec{k}\times\vec{E}}{\mu\omega} = \vec{H}$

where $\vec{H} = \frac{\vec{B}}{\mu}$

and $\frac{\vec{k}\times\vec{H}}{\omega\varepsilon} = -\vec{E}$

$\vec{k}$ is $\perp$ $\vec{H}$ and $\vec{k}$ is also $\perp$ to $\vec{E}$

Or In other words $\vec{X} \parallel \vec{E}$ and $\vec{k} \parallel \vec{E}$

S2. **(b)** Energy of electromagnetic wave is equally distributed in the form of electric and magnetic field energy, so ratio $\frac{U_E}{U_B} = \frac{1}{1}$

S3. **(a)** $E_{rms} = 720$ The average total energy density $= \frac{1}{2} \epsilon_0 \; E_0^2 = \frac{1}{2} \epsilon_0 \; [\sqrt{2}E_{rms}]^2 = \epsilon_0 \; E_{rns}^2$

$= 8.85 \times 10^{-12} \times (720)^2$

$= 4.58 \times 10^{-6} J/m^3$

S4. **(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

Radio waves 10 to 10^4

S5. **(d)** $I_d = 1\,mA = 10^{-3}\,A$

C = $2\mu F = 2 \times 10^{-6}\,F$

$I_D = I_C = \frac{d}{dt}(CV) = C\frac{dV}{dt}$

Therefore, $\frac{dV}{dt} = \frac{I_D}{C} = \frac{10^{-3}}{2\times10^{-6}} = 500\,Vs^{-1}$

Therefore, applying a varying potential difference of 500 V s^{-1}would produce a displacement current of desired value.

S6. **(c)** $E_0 = CB_0$ and C = $\frac{1}{\sqrt{\mu_0\varepsilon_0}}$

Electric energy density = $\frac{1}{2}\varepsilon_0 {E_0}^2 = \mu_E$

Magnetic energy density = $\frac{1}{2}\frac{Bo^2}{\mu_0} = \mu_B$ Thus, $\mu_E = \mu_B$

Energy is equally divided between electric and magnetic field

S7. **(c)** In an electromagnetic wave electric field and magnetic field are perpendicular to the direction of propagation of wave. The vector equation for the electric field is

$\vec{E} = E_0 \cos\left(\omega t - \frac{2\pi}{\lambda} y\right)\hat{z}$

S8. **(a)** Frequency remains constant during refraction

$v_{med} = \frac{1}{\sqrt{\mu_0\,\epsilon_0\times4}} = \frac{c}{2}$

$\frac{\lambda_{med}}{\lambda_{air}} = \frac{v_{med}}{v_{air}} = \frac{c/2}{c} = \frac{1}{2}$

$\therefore$ wavelength is halved and frequency remains unchanged.

S9. **(b)** For electromagnetic waves we know that, $\frac{E}{B} = c$

$\therefore \frac{9\times10^{-4}}{B} = 3 \times 10^8\,ms^{-1}$

B = $3 \times 10^{-12}\,T$.

S10. (a) The ozone layer absorbs the harmful ultraviolet rays coming from sun.

S11. (a) E.M. wave always propagates in a direction perpendicular to both electric and magnetic fields. So, electric and magnetic fields should be along + X – and + Y – directions respectively. Therefore, option (a) is the correct option.

S12. (d) $\frac{1}{2}\varepsilon_0 E_0^2$ is electric energy density.

$\frac{B^2}{2\mu_0}$ is magnetic energy density. So, total energy = $\frac{1}{2}\varepsilon_0\,E_0^2 + \frac{B_0^2}{2\mu_0}$

S13. (a) Given: relative permittivity, ε_r = 1.44 and relative permeability, μ_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

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

$= 2.5 \times 10^8$ m/s

S14. (c) Incident momentum, p = $\frac{E}{c}$

For perfectly reflecting surface with normal incidence

Δp = 2p = $\frac{2E}{c}$

$F = \frac{\Delta p}{\Delta t} = \frac{2E}{ct}$

$P = \frac{F}{A} = \frac{2E}{ctA}$

S15. (a) E_x and B_y would generate a plane EM wave travelling in z-direction,$\vec{E}$,$\vec{B}$ and $\vec{k}$ from a right-handed system $\vec{k}$ is along z-axis.

As $\hat{\imath} \times \hat{\jmath} = \hat{k} \Rightarrow E_x\,\hat{\imath} \times B_y\,\hat{\jmath} = C\hat{k}\; i.e., E$ is along x-axis B is along y-axis.

S16. (b) From question,

$B_0 = 20\,nT = 20 \times 10^{-9}T$

($\therefore$ velocity of light in vacuum $C = 3 \times 10^8 ms^{-1}$)

$\vec{E}_0 = \vec{B}_0 \times \vec{C}$

$|\vec{E}_0| = |\vec{B}|.|\vec{C}| = 20 \times 10^{-9} \times 3 \times 10^8\,ms^{-1}$

$\vec{E}_0 = \vec{B}_0 \times \vec{C}$

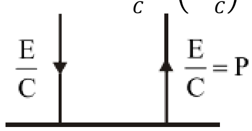
$|\vec{E}_0| = |\vec{B}|.|\vec{C}| = 20 \times 10^{-9} \times 3 \times 10^8$ = 6 V/m.

S17. (c) Microwave oven acts on the principle of giving vibrational energy to water molecules.

S18. (a) Displacement current is set up in a region where the electric field is changing with time.

S19. (a) Momentum of light falling on reflecting surface p = $\frac{E}{C}$ As surface is perfectly reflecting so momentum reflect $P^1 = \frac{E}{C} So,$ momentum transferred

$= P - P^1 = \frac{E}{C} - \left(-\frac{E}{C}\right) = \frac{2E}{C}$



S20. **(d)** (1) Infrared rays are used to treat muscular strain because these are heat rays.

(2) Radio waves are used for broadcasting because these waves have very long wavelength ranging from few centimeters to few hundred kilometers

(3) X-rays are used to detect fracture of bones because they have high penetrating power but they can't penetrate through denser medium like dones.

(4) Ultraviolet rays are absorbed by ozone of the atmosphere.

S21. **(a)** Velocity of light

$C = \frac{E}{B} \Rightarrow B = \frac{E}{C} = \frac{9.3}{3\times10^8} = 3.1 \times 10^{-8} T$

S22. **(b)** The average energy stored in the electric field

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

The average energy stored in the magnetic field = $U_B = \frac{1}{2}\frac{B^2}{\mu_0},$

According to conservation of energy $U_E = U_B$

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

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

S23. **(b)** EM waves carry momentum and hence can exert pressure on surfaces. They also transfer energy to the surface so P $\neq$ 0 and $E \neq 0$.

S24. **(b)** Velocity of em wave in a medium is given by $\vec{v} = \vec{E} \times \vec{B}$

$\therefore v\hat{\imath} = (E\hat{\jmath}) \times (\vec{B})$ $\quad [\because \vec{E} = E\hat{\jmath}\ (\text{Given})]$

As $\hat{\imath} = \hat{\jmath} \times \hat{k}$, so $\vec{B} = B\hat{k}$

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

S25. **(b)** The wave length of radiation used should be less than the size of the particle

Size of particle $= \lambda = \frac{c}{v}$

$3 \times 10^{-4} = \frac{3\times10^{10}}{v}$ or $v = 10^{14}$ hertz

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

ASSERTION AND REASONING

S1. **(a)** Shortwave radio is radio transmission using shortwave frequencies, generally 1.6–30 MHz (187.4–10.0 m), just above the medium wave AM broadcast band. Shortwave radio has an ability to enter a state of skywave or skip propagation, in which the radio waves are reflected or refracted back to Earth from the ionosphere, as opposed to being absorbed. This is a particularly important characteristic: it allows the transmitted signal to be reflected around the curve of the Earth, thus shortwave is not line-of-sight. This allows for very long-distance communications.

S2. **(a)** Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

S3. **(c)** both assertion and reason are correct and reason is the correct explanation of assertion.

S4. **(a)** The assertion and reason are true but the reason is not correct explanation of assertion. In face the energy of gamma ray is more than X-rays because the frequency of gamma ray is higher than that of X-rays as E=hv.

S5. (d)

VERY SHORT ANSWER QUESTIONS

S1. The displacement current is equal to the charging current. So, displacement current is also 0.25 A.

S2. Both electric field and magnetic fields are electromagnetic waves. These waves are perpendicular to each other and perpendicular to the direction of propagation.

S3. Microwaves with frequency range between 10^{10} to 10^{12} Hz are used in operating a RADAR.

S4. (i) Infrared rays (ii) Microwaves

S5. Infrared waves are produced by hot bodies and molecules, so are referred to as heat waves.

(i) Electromagnetic wave having short wavelength than infrared waves are visible, UV, X-rays and y-rays.

(ii) Electromagnetic wave having longer wavelength than infrared waves are microwaves, radio waves.

SHORT ANSWER QUESTIONS

S1. Properties of electromagnetic waves:

(i) Transverse nature

(ii) Does not get deflected by electric or magnetic fields

(iii) Same speed in vacuum for all waves (iv) No material medium required for propagation

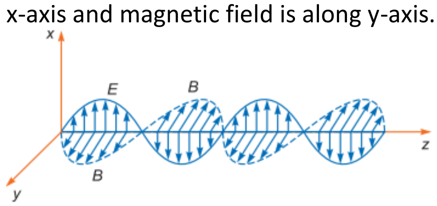
They get refracted, diffracted and polarized.

Electric charges present on a plane, kept normal to the direction of propagation of an EM wave can be set and sustained in motion by the electric and magnetic field of the electromagnetic wave. The charges thus acquire energy and momentum from the waves.

S2. During charging, electric flux between the plates of capacitor keeps on changing; this results in the production of a displacement current between the plates.

$I_d = \varepsilon_0 \left(\frac{d\varphi_E}{dt}\right)$

S3. (a) An oscillating charge produces an oscillating electric field in space, which produces an oscillating magnetic field. The oscillating electric and magnetic fields regenerate each other, and this results in the production of em waves in space. (b) Electric field is along x-axis and magnetic field is along y-axis.



S4. An oscillating or accelerated charge is supposed to be source of an electromagnetic wave. An oscillating charge produces an oscillating electric field in space which further produces an oscillating magnetic field which in turn is a source of electric field. These oscillating electric and magnetic field, hence, keep on regenerating each other and an electromagnetic wave is produced the frequency of EM wave = Frequency of oscillating charge.

S5. (a) Infra-red waves are often called heat waves because water molecules present in most materials readily absorb infrared waves. After absorption, their thermal motion increases, that is they heat up and heat their surroundings.

(b) Electromagnetic waves can set and sustain electric charges in motion by their electric and magnetic fields. The charges thus acquire energy and momentum from the waves. Since it carries momentum, an electromagnetic wave also exerts pressure, called radiation pressure. Hence, they are said to transport momentum.

NUMERICAL TYPE QUESTIONS

S1. Intensity of electromagnetic wave given is by $I = \frac{P_{av}}{4\pi r^2} = \frac{E_m^2}{2\mu_0 c}$

$E_m = \sqrt{\frac{\mu_0 c P_{av}}{2\pi r^2}} = \sqrt{\frac{(4\pi\times10^{-7})\times(3\times10^8)\times800}{2\pi\times(3.5)^2}}$ = 62.6 V/m

S2. Radio receives EM wavs (velocity of EM waves c = 3 × 10^8 m/s)

□ c = f□ □ $f = \frac{3\times10^8}{300} = 10^6$ Hz

Now $f = \frac{1}{2\pi\sqrt{LC}} = 1\times10^6$

□ $C = \frac{1}{4\pi^2\times10^{-3}\times10^{12}} = 25$ pF

S3. We are given that;

E_0 = 48 V/m, ν = 2.0 × 10^{10} Hz and c = 3 × 10^8 V/m

(a) Wavelength of the wave,

$\lambda = \frac{c}{v} = \frac{3\times10^8 m/s}{2.0\times10^{10} s^{-1}} = 1.5\times10^{-2} m$

(b) Amplitude of the oscillating magnetic field,

$B_0 = \frac{E_0}{c} = \frac{48V/m}{3\times10^8 m/s} = 1.6\times10^{-7}T$

(c) Total average energy density,

$u_{av} = \frac{1}{2}\epsilon_0 E_0^2$

$= \frac{1}{2}(8.85\times10^{-12})(48)^2$ J/m³ = 1.0×10^{-8} J/m³

S4. Average energy density is given by

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

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

$= \frac{1}{4}\varepsilon_0 E_0^2$

$= \frac{1}{4}\times 8.85\times10^{-12}\times(1)^2 = 2.2\times10^{-12}$ J/m²

S5. Total average energy density (due to both electric and magnetic fields)

$= \frac{1}{2}\epsilon_0 E_0^2 = \frac{1}{2}(8.85\times10^{-12})(1)^2 = 4.42\times10^{-12}$ J/m³

Since the energy is shared equally by the electric and magnetic fields, average energy density of the electric field

$= \frac{1}{2}(4.42\times10^{-12}$ J/m³$) = 2.21\times10^{-12}$ J/m³ average energy density of the magnetic field

$= \frac{1}{2}(4.42\times10^{-12}$ J/m³$) = 2.21\times10^{-12}$ J/m³

S6. (i) Wavelength

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

(ii) Given $E_0 = 40\text{Vm}^{-1}$

Energy density due to electric field $= \frac{1}{2}\varepsilon_0 E_{rms}^2$

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

$= \frac{1}{4}\times 8.86\times10^{-12}\times(40)^2 = 3.5\times10^{-9}\text{ J}^2\text{ m}^3$

S7. $I_d = 1\text{ mA} = 10^{-3}\text{ A}$

$C = 2\mu\text{F} = 2\times10^{-6}\text{ F}$

$I_D = I_C = \frac{d}{dt}(CV) = C\frac{dV}{dt}$

Therefore, $\frac{dV}{dt} = \frac{I_D}{C} = \frac{10^{-3}}{2\times10^{-6}} = 500\text{Vs}^{-1}$

Therefore, applying a varying potential difference of 500 V s^{-1} would produce a displacement current of desired value.

Here, $k = \frac{2\pi}{\lambda}, \omega = 2\pi v$

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

where c is the speed of electromagnetic wave in vacuum. It is a constant whose value is $3\times10^6\text{ m s}^{-1}$

Q9. The frequency of electromagnetic wave remains unchanged but the wavelength of electromagnetic wave changes when it passes from one medium to another.

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

∴ $c \propto \frac{1}{\sqrt{\varepsilon_0}}$ and $v \propto \frac{1}{\sqrt{\varepsilon}}$

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

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

S10. From question,

$B_0 = 20\text{nT} = 20 \times 10^{-9}$ T
$\vec{E}_0 = \vec{B}_0 \times \vec{C}$

$|\vec{E}_0| = |\vec{B}_0| \cdot |\vec{C}| = 20 \times 10^{-9} \times 3 \times 10^8 = 6$ V/m.
(velocity of light in vacuum $C = 3 \times 10^8\ \text{ms}^{-1}$)

HOMEWORK EXERCISE SOLUTIONS

MCQ

S1. **(b)** An accelerating charge is used to produce oscillating electric and magnetic fields, hence the electromagnetic wave.

S2. **(c)** As $\lambda = \frac{hc}{E}$
where the symbols have their usual meanings.
Here, $E = 15$ keV $= 15 \times 10^3$ eV and $hc = 1240$ eV nm
$\therefore \lambda = \frac{1240\ \text{eV nm}}{15 \times 10^3\ \text{eV}} = 0.083$ nm
As the wavelength range of X-rays is from 1 nm to 10^{-3} nm, so this wavelength belongs to X-rays.

S3. **(b)** $\lambda = \frac{3 \times 10^8}{100\ \text{Hz}} = 3 \times 10^6$ m

S4. **(b)**
$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$ (free space)
$v = \frac{1}{\sqrt{\mu\varepsilon}}$ (medium) $\therefore \mu = \frac{c}{v} = \sqrt{\frac{\mu\varepsilon}{\mu_0\varepsilon_0}}$

S5. **(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.

S6. **(b)** γ –rays has the smallest wavelength.

S7. **(b)** X-rays are used for the investigation of structure of solids.

S8. **(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.

S9. **(b)** $\lambda_m > \lambda_v > \lambda_x$.
In spectrum X-rays has minimum wavelength and microwave has maximum wavelength.

S10. **(a)** The velocity of electromagnetic radiation in vacuum is $\frac{1}{\sqrt{\mu_0 \varepsilon_0}}$, where μ_0 and ε_0 are the permeability and permittivity of vacuum.

ASSERTION AND REASONING

S1. **(a)** In the electromagnetic wave, the electric field and magnetic field are oriented in such a direction that they are perpendicular to each other and also perpendicular to the direction of propagation of the wave. Due to the perpendicular directions of the electric and magnetic fields to each other and also to the direction of propagation of the wave, the electromagnetic wave is transverse in nature. Therefore, the assertion and reason given are both correct and reason is the correct explanation for the assertion.

S2. (a) according to Maxwell's classical theory accelerated charges do produce electromagnetic waves. The oscillations of a dipole result in the production of radiations which occur because the charges in a dipole get accelerated while performing oscillations. So, the reason is also true and does explain the assertion. So, the correct answer is Option a.

S3. (d) The optical waves used in optical fibre communication are better carrier of signals than microwaves. Because the frequency of an optical wave is more than microwave The speed of microwave and optical wave is the same in vacuum and in other medium speed of microwaves is more than optical waves. So both statement is false.

S4. (a)
S5. (d)

VERY SHORT ANSWER QUESTIONS

S1. (i) The waves of maximum frequency are gamma rays.
(ii) The waves of minimum frequency are radio waves

S2. As electromagnetic waves are plane polarised, so the receiving antenna should be parallel to electric/magnetic part of the wave.

S3. Infrared waves are produced by hot bodies and molecules.

S4. On decreasing the frequency, reactance $X_C = \frac{1}{\omega C}$ will increase which will lead to decrease in conduction current. In this case $I_D = I_C$, hence displacement current will decrease.

S5. Ultraviolet radiations. Frequency range $10^{15} - 10^{17}$Hz.

SHORT ANSWER QUESTIONS

S1. **(i)** Microwave, (ii) Infrared, (iii) X-rays
Microwave are produced by special vacuum tubes, like klystrons, magnetrons and gun diodes. Infrared are produced by the vibrating molecules and atoms in hot bodies. X-rays are produced by the bombardment of high energy electrons on a metal target of high atomic weight (like tungsten).

S2. **(a)** EM waves : γ-rays Range : 10^{19} Hz to 10^{23} Hz

(b) This is because the special glass goggles protect the eyes from large amount of UV radiations produced by welding arcs.

(c) Infrared waves are called heat waves because water molecules present in the materials readily absorb the infrared rays and get heated up. Application: They are used in green houses to warm the plants.

S3. (a) If a charge particle oscillates with some frequency, produces an oscillating electric field in space, which produces an oscillating magnetic field, which in turn, is a source of electric field, and so on. Thus oscillating electric fields and magnetic fields regenerate each other, and an electromagnetic wave propagates in the space.

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

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

NUMERICAL TYPE QUESTIONS

S1. Here, $\lambda = \frac{c}{v} = \frac{3\times10^8}{8.2\times10^6} = 36.6\text{ m.}$

S2. $Here$

$B_0 = \frac{E_0}{c} = \frac{9\times10^3}{3\times10^8} = 3\times10^{-5}\text{ T}$

S3. $E = \hat{\imath}40\cos(kz - 6\times10^8 t)$

Compare the given equation with

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

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

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

S4. 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

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

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

S5. Total average energy density (due to both electric and magnetic fields)

$= \frac{1}{2}\epsilon_0 E_0^2 = \frac{1}{2}(8.85\times10^{-12})(1)^2 = 4.42\times10^{-12}\text{ J/m}^3$

Since the energy is shared equally by the electric and magnetic fields, average energy density of the electric field

$= \frac{1}{2}(4.42\times10^{-12}\text{ J/m}^3) = 2.21\times10^{-12}\text{ J/m}^3$

average energy density of the magnetic field

$= \frac{1}{2}(4.42\times10^{-12}\text{ J/m}^3) = 2.21\times10^{-12}\text{ J/m}^3$