08

We have learnt that an electric current produces magnetic field and a varying magnetic field gives rise to an electric field. This brought together the phenomena of electricity and magnetism into a coherent and unified theory. After this discovery, Maxwell predicted variation of electric and magnetic field vectors perpendicular to each other leads to electromagnetic disturbance in space. He also concluded that, electromagnetic waves could travel with the speed of light. This led him to conclude that the light itself is an electromagnetic wave.

ELECTROMAGNETIC WAVES

CHAPTER CHECKLIST
- Displacement Current
- Maxwell's Equations
- Electromagnetic Waves
- Electromagnetic Spectrum

DISPLACEMENT CURRENT

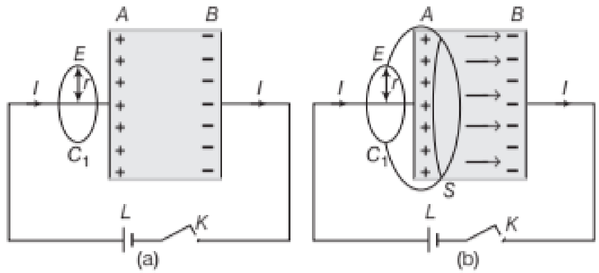
Ampere's circuital law states that, the line integral of magnetic field **B** around any closed path is equal to μ_0 times the total current threading the closed path,

$$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I \qquad \ldots\text{(i)}$$

where, I is the net current threading the surface bounded by a closed path C.

Origin of Displacement Current

According to Maxwell, the Eq. (i) is logically inconsistent. With the help of following observations, it explained the same. He considered a parallel plate capacitor having plates A and B connected to a battery L, through a tapping key K. After pressing the key K, the conduction current flows through the connecting wires and the capacitor starts storing charge. As the charge on the capacitor grows, the conduction current in the wire decreases. When the capacitor is fully charged, the conduction current stops flowing in the wire. But during the charging of capacitor, there is no conduction current between the plates of capacitor. Let at an instant during charging, I be the conduction current in the wires. This current will produce magnetic field around the wires which can be detected by using a compass needle.



Circuit diagrams showing the inconsistency of Ampere's circuital law

After this, the magnetic field was found out at point E, which is at a perpendicular distance r from connecting wire, in a region outside the parallel plate capacitor. For this, a plane circular loop C_1 of radius r is considered. Its centre lies on wire and its plane is perpendicular to the direction of current carrying wire [see Fig. (a)]. The magnitude of magnetic field is same at all points on the loop and is acting tangentially along the circumference of the loop. If B is the magnitude of magnetic field at E, then by using Ampere's circuital law for loop C_1, we get

$$\oint_{C_1} \mathbf{B} \cdot d\mathbf{l} = \oint_{C_1} B\,dl \cos 0 = B \times 2\pi r = \mu_0 I$$

$$\Rightarrow \qquad B = \frac{\mu_0 I}{2\pi r} \qquad \ldots\text{(ii)}$$

Now, a different surface, i.e. a tiffin box surface is considered. This surface is without lid with its circular rim, which has the same boundary as that of loop C_1 [see Fig. (b)].

On applying Ampere's circuital law to loop C_1 of this tiffin surface, we get

$$\oint \mathbf{B} \cdot d\mathbf{l} = B \cdot 2\pi r = \mu_0 \times 0 = 0 \qquad \ldots\text{(iii)}$$

From Eqs. (ii) and (iii), it has been noticed that there is a magnetic field at E calculated through one way and no magnetic field at E, calculated through another way.As this contradiction arises from the use of Ampere's circuital law, hence, Ampere's circuital law is logically inconsistent.

Basic Idea of Displacement Current

Since, Ampere's circuital law for conduction current during charging of a capacitor was found inconsistent. Maxwell argued that the above inconsistency of Ampere's circuital law is because of some missing term. That term must be related to a changing electric field which passes through surface S between the plates of capacitor during charging. So, Maxwell introduced this missing term, i.e. displacement current, in order to make Ampere's circuital law logically consistent. Displacement current is that current which comes into play in the region in which the electric field and the electric flux is changing with time.

i.e. Displacement current, $\boxed{I_d = \varepsilon_0 \dfrac{d\phi_E}{dt}}$

Ampere's circuital law $\left(\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I\right)$ was modified to

$$\boxed{\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 (I_c + I_d)}$$

where, I_c = conduction current and I_d = displacement current.

It is called **modified Ampere's circuital law** or **Ampere Maxwell's-circuital law**.

Therefore, modified Ampere's circuital law may also be expressed as

$$\boxed{\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 \left(I_c + \varepsilon_0 \frac{d\phi_E}{dt}\right)}$$

The inferences can be drawn from the above discussion as given below

(i) The conduction and displacement currents are individually discontinuous, but the currents together possess the property of continuity through any closed electric circuit.

(ii) The displacement current is precisely equal to the conduction current, when the two present in different parts of the circuit.

(iii) The displacement current arises due to rate of change of electric flux (or electric field) between the two plates of the capacitor.

(iv) Just as the conduction current, the displacement current is also the source of varying magnetic field.

EXAMPLE |1| In an electric circuit, there is a capacitor of reactance 100 Ω connected across the source of 220 V. Find the displacement current.

Sol. Since, displacement current = conduction current.

Therefore, $I_d = \dfrac{V}{X_C} = \dfrac{220}{100} = 2.2\,\text{A}$

EXAMPLE |2| In which way, you can establish an instantaneous displacement current of 1.0 A in the space between the parallel plates of 1 μF capacitor?

Sol. ∴ Displacement current,

$$I_d = \varepsilon_0 \frac{d\phi_E}{dt} = \varepsilon_0 \frac{d}{dt}(EA) \qquad [\because \phi_E = EA]$$

where, E is electric field and A is the area of cross-section.

$$= \varepsilon_0 A \frac{d}{dt}\left(\frac{V}{d}\right)$$

$$\Rightarrow \quad I_d = \frac{\varepsilon_0 A}{d} \times \frac{dV}{dt} = \frac{CdV}{dt} \qquad \left[\because C = \frac{\varepsilon_0 A}{d}\right]$$

$$\Rightarrow \quad \frac{dV}{dt} = \frac{I_d}{C} = \frac{1.0}{10^{-6}} = 10^6 \text{ Vs}^{-1}$$

Thus, an instantaneous displacement current of 1 A can be set up by changing the potential difference across the parallel plates of capacitor at the rate of 10^6 Vs^{-1}.

MAXWELL'S EQUATIONS

Maxwell's equations are the basic laws of electricity and magnetism. These equations give complete description of all electromagnetic interactions. Maxwell on the basis of his equations, predicted the existence of electromagnetic waves.

There are four Maxwell's equations which are explained as given below

Gauss's Law of Electrostatics

This law states that, the total electric flux through any closed surface is always equal to $\frac{1}{\varepsilon_0}$ times the net charge enclosed by that surface. It is given by

$$\oint \mathbf{E} \cdot d\mathbf{S} = \frac{q}{\varepsilon_0}$$

This equation is called **Maxwell's first equation.**

Gauss's Law in Magnetostatics

This law states that, the net magnetic flux through any closed surface is always zero. It is given by

$$\oint \mathbf{B} \cdot d\mathbf{S} = 0$$

This equation is called **Maxwell's second equation**.

Faraday's Law of Electromagnetic Induction

This law states that, the induced emf produced in a circuit is numerically equal to rate of change of magnetic flux through it. It is given by

$$\oint \mathbf{E} \cdot d\mathbf{l} = -\frac{d\phi_B}{dt}$$

This equation is called **Maxwell's third equation**.

Ampere-Maxwell's Circuital Law

This law states that, the line integral of the magnetic field along a closed path is equal to μ_0 times the total current (i.e. sum of conduction current and displacement current) threading the surface bounded by that closed path. It is given by

$$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 \left(I_c + \varepsilon_0 \frac{d\phi_E}{dt} \right)$$

This equation is called **Maxwell's fourth equation.**

ELECTROMAGNETIC WAVES

These waves are produced due to the change in electric field **E** and magnetic field **B** sinusoidally and propagating through space such that, the two fields are perpendicular to each other and perpendicular to the direction of wave propagation.

Source of Electromagnetic Waves

An oscillating charge is an example of accelerating charge. It produces an oscillating electric field in space, which produces an oscillating magnetic field, which in turn produces an oscillating electric fields and so on. The oscillating electric and magnetic fields regenerate each other as a wave which propagates through space.

The frequency of EM wave is equal to the frequency of oscillation of charge, i.e.

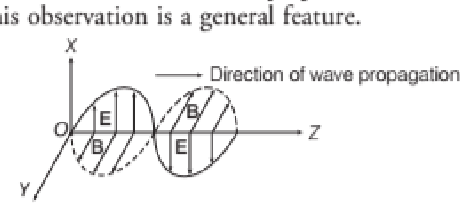
$$\nu = \frac{1}{2\pi\sqrt{LC}}$$

Electromagnetic waves are also produced when fast moving electrons are suddenly stopped by metal target of high atomic number. These electromagnetic waves are called **X-rays.**

Transverse Nature of Electromagnetic Waves

It can be shown from Maxwell's equations that electric and magnetic fields in an electromagnetic wave are perpendicular to each other and to the direction of wave propagation.

It was seen in the discussion of the displacement current also. If we would consider a parallel plate capacitor [refer to figure on page 330], the **E** inside the parallel plate capacitor was directed perpendicular to the plates. Also, the **B** which give rise to the displacement current was parallel to the capacitor . Thus, **E** and **B** were perpendicular in that case. But, this observation is a general feature.



A plane EM wave travelling along Z-axis

In the above figure, we see that permanent curve shows electric field **E** which is along x-direction and dotted curve shows magnetic field **B** which is along y-direction and the wave propagates along z-direction. Both **E** and **B** vary sinusodially and become maximum at same position and time.

Since, in electromagnetic wave, **E** and **B** are mutually perpendicular to each other, so they are transverse in nature.

The EM wave propagating in the positive z-direction may be represented by the following equations

Here, $E = E_x = E_0 \sin(kx - \omega t)$

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

where, $k = 2\pi / \lambda$, [λ = wavelength]

$\omega = 2\pi\nu$, [ν = frequency]

E_0 = amplitude of varying electric field

and B_0 = amplitude of varying magnetic field.

Important Characteristics of Electromagnetic Waves

Important characteristics of EM waves are listed below

(i) The electromagnetic waves are produced by accelerated charge.

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

(iii) These waves travel in free space with the speed of light ($3 \times 10^8 \, ms^{-1}$), given by the relation $c = 1/\sqrt{\mu_0 \varepsilon_0}$. It means that light waves are electromagnetic in nature.

(iv) Speed of electromagnetic wave in a medium is given by, $v = 1/\sqrt{\mu\varepsilon}$, where ε and μ are the permittivity and magnetic permeability of a material medium, respectively. This means, the speed of EM wave in a medium depends on electric and magnetic properties of a medium.

(v) The direction of variations of electric and magnetic fields are perpendicular to each other and also perpendicular to the direction of wave propagation. Thus, electromagnetic waves are transverse in nature.

(vi) In free space, the magnitudes of electric and magnetic fields in electromagnetic waves are related by $E_0 / B_0 = c$.

(vii) The energy in electromagnetic waves is divided, on an average, equally between electric and magnetic fields.

$$U_e = U_m$$

where, U_e = energy of electric field

and U_m = energy of magnetic field.

(viii) The energy density (energy per unit volume) in an electric field **E** in vacuum is $\frac{1}{2}\varepsilon_0 E^2$ and that in magnetic field **B** is $\frac{B^2}{2\mu_0}$.

$\therefore$ Energy associated with an electromagnetic wave is given by

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

Also, average energy density,

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

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

(ix) Electromagnetic waves, being uncharged, are not deflected by electric and magnetic fields.

(x) The electromagnetic wave like other waves carries energy and momentum. Since, it has momentum, an electromagnetic wave also exerts pressure called **radiation pressure**.

If wave is incident on a completely absorbing surface, then momentum delivered is given by

momentum, $p = \frac{U}{c}$

Note Light carries energy from the sun to the earth, thus making life possible on the earth.

(xi) Electromagnetic waves are polarised and can be easily seen in the response of a portable AM radio to a broadcasting station. If an AM radio has a telescopic antenna, it responds to the electric part of the signal. When the antenna is turned horizontal, the signal will be greatly diminished.

EXAMPLE |3| An electromagnetic wave is travelling in vacuum with a speed of 3×10^8 m / s. Find its velocity in a medium having relative electric and magnetic permeability 2 and 1, respectively.

Sol. Given, velocity of electromagnetic wave in vacuum,

$$c = 3 \times 10^8 \text{m/s}$$

Relative electric permeability, $\varepsilon_r = 2$

and magnetic permeability, $\mu_r = 1$

Since, velocity of electromagnetic wave in a medium can be calculated by

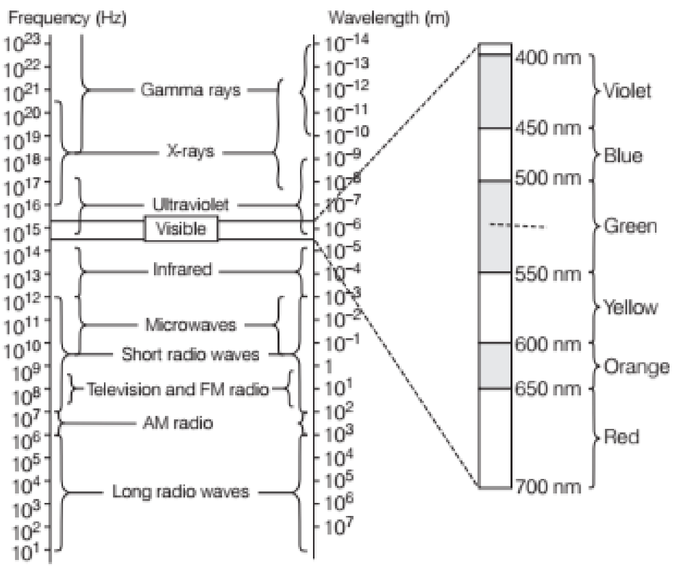
$$v = \frac{1}{\sqrt{\varepsilon_0 \varepsilon_r \mu_0 \mu_r}} = \frac{1}{\sqrt{\varepsilon_0 \mu_0} \times \sqrt{\mu_r \varepsilon_r}}$$

where, $\frac{1}{\sqrt{\varepsilon_0 \mu_0}} = c \Rightarrow v = \frac{c}{\sqrt{\mu_r \varepsilon_r}}$ ...(i)

Therefore, $v = \frac{3 \times 10^8}{\sqrt{2 \times 1}} \Rightarrow v = \frac{3}{\sqrt{2}} \times 10^8$ m/s

ELECTROMAGNETIC SPECTRUM

The orderly arrangement of EM waves in increasing or decreasing order of wavelength λ or frequency ν is called electromagnetic spectrum. The range varies from 10^{-12} m to 10^4 m, i.e. from γ-rays to radio waves.



Electromagnetic spectrum with common names for various parts of it

The wavelength ranges, frequency ranges and use of various regions of electromagnetic spectrum are summarised below

Radio waves

These are produced due to oscillating charge particles. The frequency varies from 500 kHz to 1000 MHz.

Uses of radio waves are given below

(i) These are used in AM (Amplitude Modulation) from 530 kHz to 1710 kHz. These are also used in ground wave propagation.

(ii) These are used in TV waves ranging from 54 MHz to 890 MHz.

(iii) These are used in FM (Frequency Modulation) ranging from 88 MHz to 108 MHz.

(iv) UHF (Ultra High Frequency) waves are used in cellular phones.

Microwaves

These waves are called **short wavelength radio waves** which are produced by vacuum tubes. Their frequency lies in the range of 1 GHz to 300 GHz (gigahertz).

Uses of microwaves are given below

(i) These are used in RADAR systems for aircraft navigation.

(ii) These are used in microwave oven for cooking purpose.

(iii) These are used in study of atomic and molecular structures.

(iv) These are used to measure the speed of vehicle, speed of cricket ball, etc.

Infrared Waves

These waves were discovered by Herschell. These waves are also called **heat waves**. These waves are produced from the heat radiating bodies and molecules.

They have high penetration power. Its frequency range is from 3×10^{11} Hz to 4×10^{14} Hz.

Uses of infrared waves are given below

(i) These are used in physical therapy.

(ii) These are used in satellite for army purpose.

(iii) These are used in weather forecasting.

(iv) These are used for producing dehydrated fruits.

(v) These are used in solar water heater, solar cells and cooker.

Visible Rays

It is that part of spectrum which is visible by human eye and its frequency range is from 4×10^{14} Hz to 7×10^{14} Hz.

Uses of visible rays are given below

Visible rays are used by the optical organs of humans and animals for three primary purposes given below:

(i) To see things, avoid bumping from them and escape danger.

(ii) To find stuff to eat.

(iii) To find other living things with which to consort so as to prolong the species.

Ultraviolet Rays

These rays were discovered by Ritter in 1801. These rays are produced by special lamps and very hot bodies. The sun is an important source of UV-rays but fortunately absorbed by ozone layer at an altitude of about 40-50km. Its frequency range is from 10^{14} Hz to 10^{16} Hz.

Uses of ultraviolet rays are given below

(i) These are used in burglar alarm.
(ii) These are used in checking mineral sample.
(iii) These are used to study molecular structure.
(iv) To kill germs in minerals.
(v) To sterilise surgical instruments.
(vi) These rays can be focussed into very narrow beams for high precision applications such as LASIK eye surgery.

X-Rays

These rays were discovered by German professor Roentgen. Its frequency range is from 3×10^{16} Hz to 3×10^{21} Hz.

Uses of X-rays are given below

(i) These are used in surgery to detect the fracture, diseased organs, stones in the body, etc.
(ii) These are used in engineering to detect fault, crack on bridges, testing of welds.
(iii) These are used at metro station to detect metal or explosive material.
(iv) These are used in scientific research.

Gamma (γ) Rays

These rays were discovered by Rutherford. They travel with the speed of light and having high penetration power. The frequency ranges from 3×10^{18} Hz to 5×10^{22} Hz.

Uses of gamma (γ) rays are given below

(i) These are used to produce nuclear reaction.
(ii) These are used in radio therapy for the treatment of tumour and cancer.
(iii) These are used in food industry to kill pathogenic microorganism.
(iv) These are used to provide valuable information about the structure of atomic nucleus.

Different Types of Electromagnetic Waves

Type	Wavelength range	Production	Detection
Radio wave	> 0.1 m	Rapid acceleration and decelerations of electrons in aerials	Receiver's aerials
Microwave	0.1 m to 1 mm	Klystron valve or magnetron valve	Point contact diodes
Infrared wave	1 mm to 700 nm	Vibration of atoms and molecules	Thermopiles bolometer, Infrared photographic film
Light	700 nm to 400 nm	Electrons in atoms emit light when they move from higher energy level to a lower energy level	The eye, Photocells, Photographic film
Ultraviolet rays	400 nm to 1 nm	Inner shell electrons in atoms moving from higher energy level to a lower energy level	Photocells, Photographic film
X-rays	1 nm to 10^{-3} nm	X-ray tubes or inner shell electrons	Photographic film, Geiger tubes, Ionisation chamber
Gamma rays	$< 10^{-3}$ nm	Radioactive decay of the nucleus	Photographic film, ionisation chamber

Note This EM spectrum and its properties have been frequently asked in previous years 2014, 2013, 2012, 2011, 2010.

CHAPTER PRACTICE (SOLVED)

OBJECTIVE Type Questions

1. Which statement represents the symmetrical counterpart of Faraday's law and a consequence of the displacement current being a source of a magnetic field?

(a) An electric field changing with time gives rise to a magnetic field
(b) A magnetic field changing with time gives rise to an electric field
(c) An emf changing with time gives rise to an electric field
(d) An displacement current, changing with time gives rise to an electric field

2. A linearly polarised electromagnetic wave given as $\mathbf{E} = E_o \hat{\mathbf{i}} \cos(kz - \omega t)$ is incident normally on a perfectly reflecting infinite wall at $z = a$. Assuming that the material of the wall is optically inactive, the reflected wave will be given as

(a) $\mathbf{E}_r = E_o \hat{\mathbf{i}}(kz - \omega t)$
(b) $\mathbf{E}_r = E_o \hat{\mathbf{i}} \cos(kz + \omega t)$
(c) $\mathbf{E}_r = -E_o \hat{\mathbf{i}} \cos(kz + \omega t)$
(d) $\mathbf{E}_r = E_o \hat{\mathbf{i}} \sin(kz - \omega t)$

3. Radiations of intensity 0.5 Wm^{-2} are striking a metal plate. The pressure on the plate is

(a) 0.166×10^{-8} Nm^{-2}
(b) 0.332×10^{-8} Nm^{-2}
(c) 0.111×10^{-8} Nm^{-2}
(d) 0.083×10^{-8} Nm^{-2}

4. Total energy density of electromagnetic waves in vacuum is given by the relation

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

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

5. The speed of electromagnetic wave in vacuum depends upon the source of radiation

(a) increases as we move from γ-rays to radio waves

(b) decreases as we move from γ-rays to radio waves

(c) is same for all of them

(d) None of the above

6. One requires 11 eV of energy to dissociate a carbon monoxide molecule into carbon and oxygen atoms. The minimum frequency of the appropriate electromagnetic radiation to achieve the dissociation lies in **NCERT Exemplar**

(a) visible region (b) infrared region

(c) ultraviolet region (d) microwave region

VERY SHORT ANSWER Type Questions

7. A capacitor has been charged by a DC source. What are the magnitude of conduction and displacement current when it is fully charged? **Delhi 2013**

8. 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 and separation = d). Neglecting the edge effects, find the displacement current through the capacitor. **NCERT Exemplar**

9. A variable frequency AC source is connected to a capacitor. How will the displacement current change with decrease in frequency? **NCERT Exemplar**

10. The charging current for a capacitor is 0.25 A. What is the displacement current across its plates? **Foreign 2016**

11. What are the directions of electric and magnetic field vectors relative to each other and relative to the direction of propagation of electromagnetic waves? **All India 2012**

12. A charged particle oscillates about its mean position with frequency 10^9 Hz. What is the frequency of electromagnetic wave produced by the oscillators? **NCERT**

13. In which directions do the electric and magnetic field vectors oscillate in an electromagnetic wave propagating along the X-axis? **All India 2017**

14. How is the speed of electromagnetic waves in vacuum determined by the electric and magnetic fields? **Delhi 2017**

15. Do electromagnetic waves carry energy and momentum? **All India 2017**

16. An electromagnetic wave exerts pressure on the surface on which it is incident. Justify. **Delhi 2014**

17. To which part of the electromagnetic spectrum does a wave of frequency 5×10^{19} Hz belong? **All India 2014**

18. Name the type of electromagnetic wave used in food industry to will pathogenic microorganism. Also write its frequency range.

19. What physical quantity is the same for X-rays of wavelength 10^{-10} m, red light of wavelength 6800 Å and radio waves of wavelength 500 m? **NCERT**

20. Why are microwaves considered suitable for radar systems used in aircraft navigation? **Delhi 2016**

21. Name the electromagnetic waves which

(i) maintain the earth's warmth and

(ii) are used in aircraft navigation. **Foreign 2012**

22. Name the electromagnetic waves used in LASIK eye surgery and why?

23. Name the electromagnetic radiations used for (a) water purification, and (b) eye surgery. **CBSE 2018**

24. Why does microwave oven heats up a food item containing water molecules most efficiently? **NCERT Exemplar**

SHORT ANSWER Type Questions

25. When an ideal capacitor is charged by a DC battery, no current flows. However, when an AC source is used, the current flows continuously. How does one explain this, based on the concept of displacement current? **Delhi 2012**

26. A capacitor made of two parallel plates each of the plate A and separation d, is being charged by an external AC source. Show that the displacement current inside the capacitor is the same as the current charging the capacitor. **All India 2013**

27. (i) An electromagnetic wave is travelling in a medium with a velocity $\mathbf{v} = v\,\hat{\mathbf{i}}$. Draw a sketch showing the propagation of the electromagnetic wave indicating the direction of the oscillating electric and magnetic fields.

(ii) How are the magnitudes of the electric and magnetic fields related to velocity of the electromagnetic wave?

Delhi 2013, All India 2008C

28. Even though an electric field E exerts a force qE on a charged particle yet electric field of an electromagnetic wave does not contribute to the radiation pressure (but transfers energy). Explain. **NCERT Exemplar**

29. Show that the radiation pressure exerted by an EM wave of intensity I on a surface kept in vacuum is $\frac{I}{c}$. **NCERT Exemplar**

30. Poynting vectors is defined as a vector whose magnitude is equal to the wave intensity and whose direction is along the direction of wave propagation. Mathematically, it is given by $\mathbf{S} = \frac{1}{\mu_0}(\mathbf{E} \times \mathbf{B})$. Show the nature of $\mathbf{S}$ *versus* t graph. **NCERT Exemplar**

31. Identify the electromagnetic waves whose wavelengths vary as

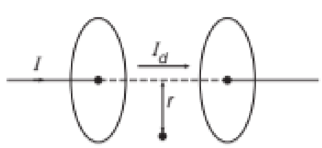
(i) $10^{-12}\text{ m} < \lambda < 10^{-8}\text{ m}$ (ii) $10^{-3}\text{ m} < \lambda < 10^{-1}\text{ m}$

Write one use for each. **All India 2017**

32. (a) Why are infrared waves often called heat waves? Explain.

(b) What do you understand by the statement, "electromagnetic waves transport momentum"? **CBSE 2018**

33. Show that the magnetic field B at a point in between the plates of a parallel plate capacitor during charging is $\frac{\mu_0 \varepsilon_0 r}{2} \cdot \frac{dE}{dt}$ (symbols having usual meaning). **NCERT Exemplar**



34. A capacitor of capacitance C is being charged by connecting it across a DC source along with an ammeter. Will the ammeter show a momentary deflection during the process of charging? If so, how would you explain this momentary deflection and the resulting continuity of current in the circuit? Write the expression for the current inside the capacitor. **All India 2012**

LONG ANSWER Type I Questions

35. Write the expression for the generalised form of Ampere's circuital law.

Discuss its significance and describe briefly how the concept of displacement current is explained through charging/discharging of a capacitor in an electric circuit. **Delhi 2015**

36. Show that average value of radiant flux density S over a single period T is given by $S = \frac{1}{2c\mu_0} E_0^2$. **NCERT Exemplar**

37. How are electromagnetic waves produced by oscillating charges?

Draw a sketch of linearly polarised electromagnetic waves propagating in the z-direction. Indicate the directions of the oscillating electric and magnetic fields. **Delhi 2016**

38. (i) Describe briefly how electromagnetic waves are produced by oscillating charges?

(ii) Give one use of each of the following

(a) Microwaves **All India 2011C**

(b) X-rays

(c) Infrared rays

(d) Gamma rays

39. Name the electromagnetic waves, in the wavelength range 10 nm to 10^{-3} nm. How are these waves generated? Write their two uses. **All India 2017 C**

40. Answer the following questions.

(i) Name the electromagnetic waves which are used for the treatment of certain forms of cancer. Write their frequency range.

(ii) Thin ozone layer on top of stratosphere is crucial for human survival. Why?

(iii) Why is the amount of the momentum transferred by the electromagnetic waves incident on the surface so small? **Delhi 2014**

41. Answer the following questions.

(i) Name the electromagnetic waves which are produced during radioactive decay of a nucleus. Write their frequency range.

(ii) Welders wear special glass goggles while working. Why? Explain.

(iii) Why are infrared waves often called as heat waves? Give their one application. **Delhi 2014**

42. Name the parts of the electromagnetic spectrum which is

(i) suitable for RADAR systems in aircraft navigations.

(ii) used to treat muscular strain.

(iii) used as a diagnostic tool in medicine.

Write in brief, how these waves can be produced? **All India 2015**

43. Name the following constituent radiations of electromagnetic spectrum which

(i) produce intense heating effect.

(ii) is absorbed by the ozone layer in the atmosphere.

(iii) is used for studying crystal structure. Write one more application for each of these radiations.

44. Identify the part of the electromagnetic spectrum which is

(i) suitable for radar system used in aircraft navigation.

(ii) produced by bombarding a metal target by high speed electrons. **All India 2016**

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

(ii) Which EM waves lie near the high frequency end of visible part of EM spectrum? Give its one use. In what way, this component of light has harmful effects on humans? **Foreign 2016**

NUMERICAL PROBLEMS

46. The current in a circuit containing a capacitor is 0.15 A. What is the displacement current and where does it exist?

47. You are given a 2 μF parallel plate capacitor. How would you establish an instantaneous displacement current of 1 mA in the space between its plates? **NCERT Exemplar**

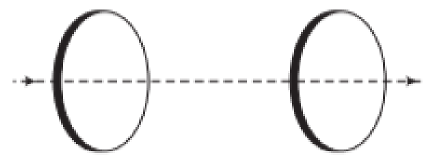
48. Calculate the displacement current between the square plates of side 1 cm of a capacitor, if electric field between the plates is changing at the rate of 3×10^6 V m^{-1} s^{-1}.

49. Figure shows a capacitor made of two circular plates each of radius 12 cm and separated by 5.0 cm. The capacitor is being charged by an external source (not shown in the figure). The charging current is constant and equal to 0.15 A.

(i) Calculate the capacitance and the rate of change of potential difference between the plates.

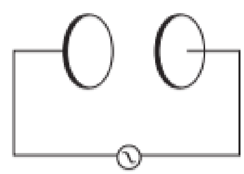
(ii) Obtain the displacement current across the plates.

(iii) Is Kirchhoff's first rule (junction rule) valid at each plate of the capacitor? Explain.



NCERT

50. A parallel plate capacitor (shown in the figure) made of circular plates each of radius $R = 6.0$ cm has a capacitance $C = 100$ pF. The capacitor is connected to a 230 V AC supply with angular frequency of 300 rad/s.



(i) What is the rms value of the conduction current?

(ii) Is the conduction current equal to the displacement current?

(iii) Determine the amplitude of **B** at a point 3.0 cm from the axis between the plates. **NCERT**

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

(ii) If the frequency of the wave is 30 MHz. What is its wavelength? **NCERT; Delhi 2012**

52. A radio can tune into any station in the 7.5 MHz to 12 MHz band. What is its corresponding wavelength? **NCERT**

53. The magnetic field of a beam emerging from a fitter facing a floodlight is given by

$$B = 12 \times 10^{-8} \sin (1.20 \times 10^7 \, z - 3.60 \times 10^{15} t) \text{T}.$$

What is the average intensity of the beam? **NCERT Exemplar**

54. About 5% of the power of a 100 W light bulb is connected to visible radiation. What is the average intensity of visible radiation at

(i) distance of 1 m from the bulb

(ii) distance of 10 m? Assume that the radiation is emitted isotropically and neglect reflection. **NCERT**

55. The amplitude of the magnetic field part of a harmonic electromagnetic wave in vacuum is $B_0 = 510$ nT. What is the amplitude of the electric field part of the wave? **NCERT**

56. In a plane, electric field oscillates sinusoidally at a frequency of 2×10^{10} Hz and amplitude 48 V/m.

(i) What is the wavelength of the wave?

(ii) What is the amplitude of the oscillating magnetic field?

(iii) Show that the average energy density of the **E** field equals the average energy density of the **B** field. **NCERT**

57. Suppose that the electric field amplitude of an electromagnetic wave is $E_0 = 120$ N/C and that its frequency is $\nu = 50.0$ MHz. (i) Determine B_0, ω, k and λ. (ii) Find expressions for **E** and **B**.

NCERT

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

$$E = [3.1 \cos\{1.8\, y + (5.4\times10^6 t)\}]\ \hat{\mathbf{i}}$$

(i) What is the direction of propagation?

(ii) What is the wavelength λ?

(iii) What is the frequency ν?

(iv) What is the amplitude of the magnetic field part of the wave?

(v) Write an expression for the magnetic field part of the wave. **NCERT**

59. Use the formula, $\lambda_m T = 0.29$ cm-K to obtain the characteristic temperature ranges for different parts of the electromagnetic spectrum. What do the numbers that you obtain, tell you? **NCERT**

60. Given below are some famous numbers associated with electromagnetic radiations in different contexts in Physics. State the part of the electromagnetic spectrum to which each belongs.

(i) 21 cm (wavelength emitted by atomic hydrogen in interstellar space).

(ii) 1057 MHz (frequency of radiation arising from two close energy levels in hydrogen, known as Lamb shift).

(iii) 2.7 K (temperature associated with the isotropic radiation filling all space thought to be a relic of the big-bang origin of the universe).

(iv) 5890 Å-5896 Å (double lines of sodium).

(v) 14.4 keV (energy of a particular transition in ^{57}Fe nucleus associated with a famous high resolution spectroscopic method (Mössbauer spectroscopy). **NCERT**

61. The terminology of different parts of the electromagnetic spectrum is given in the text.

Use the formula $E = h\nu$ (for energy of a quantum of radiation: photon) and obtain the photon energy in units of eV for different parts of the electromagnetic spectrum. In what way are the different scales of photon energies that you obtain related to the sources of electromagnetic radiation? **NCERT**

HINTS AND SOLUTIONS

1. (a) The fact that an electric field changing with time gives rise to a magnetic field, is the symmetrical counterpart and is a consequence of the displacement current being a source of a magnetic field.

2. (b) When a wave is reflected from denser medium, then the type of wave doesn't change but only its phase changes by 180° or π radian.

Thus, for the reflected wave $\hat{\mathbf{z}} = -\hat{\mathbf{z}}, \hat{\mathbf{i}} = -\hat{\mathbf{i}}$ and additional phase of π in the incident wave.

Given, here the incident electromagnetic wave is,

$$\mathbf{E} = E_o \hat{\mathbf{i}} \cos(kz - \omega t)$$

The reflected electromagnetic wave is given by

$$\mathbf{E}_r = E_o(-\hat{\mathbf{i}}) \cos[k(-z) - \omega t + \pi]$$
$$= -E_o \hat{\mathbf{i}} \cos[-(kz + \omega t) + \pi]$$
$$= E_o \hat{\mathbf{i}} \cos[-(k_Z + \omega t) = E_o \hat{\mathbf{i}} \cos(kz + \omega t)]$$

3. (a) Intensity or power per unit area of the radiations

$$I = pc \;\Rightarrow\; p = \frac{I}{c} = \frac{0.5}{3\times10^8} = 0.166\times10^{-8}\ \text{Nm}^{-2}$$

4. (d) The energy in EM waves is divided equally between the electric and magnetic fields.

The total energy per unit volume is $u = u_e + u_m$

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

5. (c) Speed of electromagnetic waves in vacuum = $\frac{1}{\sqrt{\mu_0 \varepsilon_0}}$

6. (c) Given, energy required to dissociate a carbon monoxide molecule into carbon and oxygen atoms $E = 11\text{ eV}$

We know that, $E = h\nu$, where $h = 6.62 \times 10^{-34}$ J-s

ν = frequency

$\Rightarrow$ 11 eV = $h\nu$

$$\Rightarrow \quad \nu = \frac{11 \times 1.6 \times 10^{-19}}{h}\text{ J}$$

$$= \frac{11 \times 1.6 \times 10^{-19}}{6.62 \times 10^{-34}}\text{ J} = 2.65 \times 10^{15}\text{ Hz}$$

This frequency radiation belongs to ultraviolet region.

7. Electric flux through plates of capacitor, $\phi_E = \frac{q}{\varepsilon_0}$.

where, charge, q = constant (as the capacitor is fully charged)

Displacement current, $I_d = \varepsilon_0 \frac{d\phi_E}{dt} = \varepsilon_0 \frac{d\left(\frac{q}{\varepsilon_0}\right)}{dt} = 0$

Conduction current, $I_c = C\frac{dV}{dt} = 0$ (as voltage becomes constant when the capacitor becomes fully charged).

8. The displacement current through the capacitor is given by

$$I_d = I_c = \frac{dq}{dt} \quad \text{...(i)}$$

Given, $q = q_0 \cos 2\pi\nu t$

Differentiating w.r.t. t on both sides, we get

$$\frac{dq}{dt} = q_0(-\sin 2\pi\nu t)(2\pi\nu)$$

Putting the value of $\frac{dq}{dt}$ in Eq. (i), we get

$$I_d = I_c = -(q_0 \sin 2\pi\nu t) \times 2\pi\nu = -2\pi\nu q_0 \sin 2\pi\nu t$$

9. Capacitive reactance, $X_C = \frac{1}{\omega C} = \frac{1}{2\pi\nu C}$

$$\therefore \quad X_C \propto \frac{1}{\nu}$$

As frequency decreases, X_C increases. As the conduction current is inversely proportional to X_C $\left[\because I \propto \frac{1}{X_C}\right]$.

So, displacement current also decreases because the conduction current is equal to the displacement current.

10. The displacement current is equal to 0.25 A, as the charging current is 0.25 A.

11. Direction of electric field **E**, direction of magnetic field **B** and direction of propagation of wave are mutually perpendicular to one another.

12. The frequency of electromagnetic wave produced by the oscillators is same as that of oscillating charged particle about its equilibrium position, i.e. 10^9 Hz.

13. **E** and **B** are perpendicular to direction of propagation of light. Also, direction of propagation is parallel to **E** × **B**. Hence, **E** is along **j** or $+Y$-axis and **B** is along **k** or $+Z$-axis.

14. To determine speed of light in vacuum, we use the formula, $c = \frac{E_0}{B_0} = \frac{E_{rms}}{B_{rms}}$

where, E_0 and B_0 are maximum electric field and magnetic field component respectively, of electromagnetic waves.

15. Yes, electromagnetic waves carry energy and momentum.

Momentum, $p = \frac{U}{c}$ and energy density = $\frac{1}{2}\varepsilon_0 E^2$

16. Electromagnetic wave carries energy and momentum. Since, it has momentum due to this reason it exert pressure, called radiation pressure.

17. A wave of frequency 5×10^{19} Hz belongs to γ-rays of electromagnetic spectrum.

18. Gamma(γ) rays are used in food industry to will pathogenic microorganism. Its frequency ranges from 3×10^{18} Hz to 5×10^{22} Hz.

19. Speed remains same but wavelength changes.

20. Microwaves are generally used in RADAR system and aircraft due to the fact that, they have longer wavelengths and low frequencies, so they can be focused along a straight line without much deviation. Also, they do not bend around the corners of the abstacles.

21. (i) Infrared rays (ii) Microwaves

22. In LASIK eye surgery, ultraviolet rays are used because of their short wavelength they can be focused into very narrow beam.

23. (a) Ultraviolet radiation
(b) Infrared radiation

24. Microwave oven heats up the food items containing water molecules most efficiently because the frequency of microwaves matches the resonant frequency of water molecules.

25. If an ideal capacitor is charged by DC battery, current flows momentarily till capacitor gets fully charged after that no current flow. However, when an AC source is connected, then conduction current, $I_c = \frac{dq}{dt}$ starts flowing in the connecting wire. As charging polarity of AC current changes, the capacitor is alternatively charged and discharged with time. This causes change in electric field between plates of the capacitor which causes electric flux to change and gives rise to displacement current in the region between plates of capacitor, as displacement current, $I_d = E_0 \frac{d\phi_E}{dt}$ and

$I_d = I_c$ at all instants.

26. Let the alternating emf charging the plates of capacitor be $V = V_0 \sin \omega t$ ...(i)

Charge on the capacitor,

$$q = CV = CV_0 \sin \omega t \quad \text{[from Eq.(i)]}$$

and instantaneous current, $I = \frac{dq}{dt} = \frac{d}{dt}(CV_0 \sin \omega t)$

$$= \omega CV_0 \cos \omega t = I_0 \cos \omega t$$

where, $I_0 = \omega CV_0$

Displacement current, $I_d = \varepsilon_0 \frac{d\phi_E}{dt}$

$$\Rightarrow \varepsilon_0 A \frac{d(E)}{dt} = \varepsilon_0 A \frac{d}{dt}\left(\frac{q}{\varepsilon_0 A}\right) = \varepsilon_0 A \frac{d}{dt}\left(\frac{CV_0 \sin \omega t}{\varepsilon_0 A}\right)$$

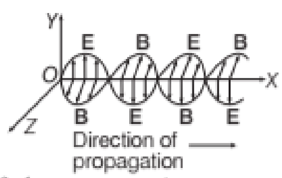
$$= \frac{d}{dt}(CV_0 \sin \omega t)$$

$$= \omega CV_0 \cos \omega t$$

$$= I_0 \cos \omega t$$

Thus, the displacement current inside the capacitor is the same as the current charging the capacitor.

27. (i) Given that velocity $\mathbf{v} = v\,\hat{\mathbf{i}}$, i.e. the wave is propagating along X-axis, so electric field **E** is along Y-axis and magnetic field **B** is along Z-axis. The propagation of electromagnetic wave is shown in the figure.



(ii) Speed of electromagnetic wave can be given as

$$c = \frac{E_0}{B_0} = \frac{E}{B}$$

where, E_0 and B_0 are peak values of E and B or instantaneous values of E and B.

28. Electric field of an electromagnetic wave is an oscillating field which causes force on the charged particle. This electric force averaged over an integral number of cycles is zero, because its direction changes with every half cycle. So, electric field is not responsible for radiation pressure.

29. Pressure $= \frac{\text{Force}}{\text{Area}} = \frac{F}{A}$

Force is the rate of change of momentum,

i.e. $F = \frac{dp}{dt}$

Energy in time dt, $U = p \cdot c \Rightarrow p = \frac{U}{c}$

$$\therefore \text{Pressure} = \frac{1}{A} \cdot \frac{U}{c \cdot dt}$$

$$= \frac{I}{c} \quad \left[\because I = \text{ intensity } = \frac{U}{A \cdot dt}\right]$$

30. Consider an electromagnetic waves with **E** be varying along Y-axis, **B** be along Z-axis and propagation of wave be along X-axis. Then, $\mathbf{E} \times \mathbf{B}$ will indicate the direction of propagation of energy flow in electromagnetic wave which will be along X-axis.

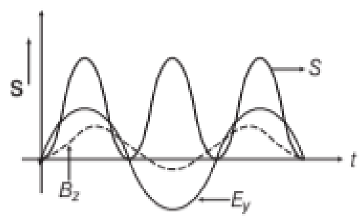
Let $\mathbf{E} = E_0 \sin(\omega t - kx)\hat{\mathbf{j}}$

$\mathbf{B} = B_0 \sin(\omega t - kx)\,\hat{\mathbf{k}}$

$$\mathbf{S} = \frac{1}{\mu_0}(\mathbf{E} \times \mathbf{B}) = \frac{1}{\mu_0} E_0 B_0 \sin^2(\omega t - kx)[\hat{\mathbf{j}} \times \hat{\mathbf{k}}]$$

$$= \frac{E_0 B_0}{\mu_0} \sin^2(\omega t - kx)\hat{\mathbf{i}} \quad [\because \hat{\mathbf{j}} \times \hat{\mathbf{k}} = \hat{\mathbf{i}}]$$

The variation of $|\mathbf{S}|$ with time t will be as given in the figure below



31. (i) 10^{-12} m - 10^{-8} m = 0.01 Å-100Å $\rightarrow$ X-ray.

It is used in crystallography.

(ii) 10^{-3} m- 10^{-1} m = 0.1 cm-10 cm $\rightarrow$ Radio waves.

It is used in radio communication.

32. (a) Infrared waves have frequencies lower than those of visible light, vibrate not only the electrons, but also the entire atoms or molecules in the structure of the surface.

This vibration increases the internal energy and hence the temperature of the structure, which is why infrared waves are often called heat waves.

(b) Electromagnetic wave transports linear momentum as it travels through space. If an electromagnetic wave transfer a total energy U to a surface in time t, then total linear momentum delivered to the surface is given as

$$p = \frac{U}{c}$$

where, c is the speed of electromagnetic wave.

33. In the given figure, I_d is the displacement current in the region between two plates of parallel plate capacitor.

The magnetic field induction at a point in a region between two plates of capacitor at a perpendicular distance r from the axis of plates is given by

$$B = \frac{\mu_0 2I_d}{4\pi r} = \frac{\mu_0}{2\pi r} I_d$$

$$= \frac{\mu_0}{2\pi r} \times \varepsilon_0 \frac{d\phi_E}{dt} \quad \left[\because I_d = \frac{\varepsilon_0 d\phi_E}{dt}\right]$$

$$= \frac{\mu_0 \varepsilon_0}{2\pi r} \frac{d}{dt}(E\,\pi r^2) \qquad [\because \phi_E = E\,\pi r^2]$$

$$= \frac{\mu_0 \varepsilon_0}{2\pi r} \pi r^2 \frac{dE}{dt} = \frac{\mu_0 \varepsilon_0 r}{2} \cdot \frac{dE}{dt}$$

34. Yes, the ammeter will show the momentary deflection.

This momentary deflection occurs due to the fact that the conducting current flows through connecting wires during the charging of capacitor. This leads to deposition of charge at two plates and hence, varying electric field of increasing nature is produced between the plates which in turn produces displacement current in space between two plates, which maintains the continuity with the conduction current.

$$I_c = I_d$$

i.e. Current inside the capacitor = Displacement current.

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

35. Refer to text on page 329.

36. Radiant flux density,

$$S = \frac{1}{\mu_0}(\mathbf{E} \times \mathbf{B}) = c^2 \varepsilon_0 (\mathbf{E} \times \mathbf{B}) \quad \left[\because c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}\right]$$

Suppose electromagnetic waves are propagating along X-axis, the electric field vector of electromagnetic waves be along Y-axis and magnetic field vector be along Z-axis. Therefore,

$$\mathbf{E} = \mathbf{E}_0 \cos(kx - \omega t)$$

and $$\mathbf{B} = \mathbf{B}_0 \cos(kx - \omega t)$$

$$\therefore \frac{1}{\mu_0}(\mathbf{E} \times \mathbf{B}) = \frac{1}{\mu_0}(\mathbf{E}_0 \times \mathbf{B}_0) \cos^2 (kx - \omega t)$$

$$S = c^2 \varepsilon_0 (E \times B) = c^2 \varepsilon_0 |(E_0 \times B_0)| \cos^2 (kx - \omega t)$$

Average value of the magnitude of radiant flux density over complete cycle,

$$S_{av} = c^2 \varepsilon_0 |\mathbf{E}_0 \times \mathbf{B}_0| \frac{1}{T} \int_0^T \cos^2 (kx - \omega t)\, dt$$

$$= c^2 \varepsilon_0 E_0 B_0 \times \frac{1}{T} \times \frac{T}{2} \quad \left[\because \int_0^T \cos^2 (kx - \omega t)\, dt = \frac{T}{2}\right]$$

$$= \frac{c^2}{2} \varepsilon_0 E_0 \left(\frac{E_0}{c}\right) = \frac{c}{2} \varepsilon_0 E_0^2 \qquad \left[\text{as, } c = \frac{E_0}{B_0}\right]$$

$$= \frac{c}{2} \times \frac{1}{c^2 \mu_0} E_0^2 \qquad \left[\because c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} \text{ or } \varepsilon_0 = \frac{1}{c^2 \mu_0}\right]$$

$$= \frac{E_0^2}{2\mu_0 c}$$

37. Refer to text on page 330.

38. (i) Refer to text on page 330.
(ii) Refer to text on pages 332 and 333.

39. Refer to text on pages 332 and 333.

40. (i) γ-rays. Its frequency range is from 3×10^{19} Hz to 3×10^{23} Hz.

(ii) The thin ozone layer on top of stratosphere absorbs most of the harmful ultraviolet rays coming from the sun towards the earth. They include UVA, UVB and UVC radiations which can destroy the life system on the earth. Hence, this layer is crucial for human survival.

(iii) Momentum transferred = Energy/Speed of light

$$= \frac{E}{c} \quad = \frac{h\nu}{c} = 10^{-22}$$

Thus, the amount of the momentum transferred by the electromagnetic waves incident on the surface is very small.

41. (i) γ-rays. Its frequency range is from 3×10^{19} Hz to 3×10^{23} Hz.

(ii) Welders wear special glass goggles to protect the eyes from ultraviolet rays.

(iii) Infrared waves are produced by hot bodies, so they are called heat waves. They are used in physical therapy,weather forecasting, etc.

42. (i) Microwaves are suitable for RADAR systems that are used in aircraft navigation. These rays are produced by special vacuum tubes, namely klystrons, magnetrons and gunn diodes.

(ii) Infrared rays are used to treat muscular strain. These rays are produced by hot bodies and molecules.

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

43. Refer to text on pages 332 and 333.

44. Refer to text on pages 332 and 333.

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

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

46. We know that, conduction current I_c is equal to the displacement current I_d.

i.e. $$I_c = I_d = 0.15 \text{ A} \qquad \text{[given]}$$

It exists across the capacitor plates.

47. Refer to Example 2 on pages 329 and 330.

So, by applying a varying potential difference of 500V/s, we would produce a displacement current of desired value.

48. We know that, $I_d = \varepsilon_0 A \frac{dE}{dt}$

where, $\varepsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2\ \text{N}^{-1}\text{m}^{-2}$

Area, $A = 1\text{ cm}^2 = 10^{-4}\text{ m}^2$

$\because \quad \frac{dE}{dt} = 3\times10^6\text{ Vm}^{-1}\text{ s}^{-1}$

$\therefore \quad I_d = 8.85\times10^{-12}\times10^{-4}\times3\times10^6 = 27\times10^{-9}\text{ A}$

49. Given, radius of plates, $r = 12\text{ cm} = 12\times10^{-2}\text{ m}$

Separation of two circular plates, $d = 5\text{ cm}$
$= 5\times10^{-2}\text{ m}$

Current, $I = 0.15\text{ A}$

(i) Capacitance of parallel plate capacitor, $C = \frac{\varepsilon_0 A}{d}$

where, A is the area of plates.

$$\therefore \quad C = \frac{8.854\times10^{-12}\times3.14\,(12\times10^{-2})^2}{5\times10^{-2}}$$
$$= 800.68\times10^{-14}\text{ F}$$
$$= 8.01\times10^{-12}\text{F} = 8.01\text{ pF}$$

Charge on the plates of the capacitor, $q = CV$

$$\Rightarrow \quad \frac{dq}{dt} = C\cdot\frac{dV}{dt}$$
$$\Rightarrow \quad I = C\cdot\frac{dV}{dt} \qquad \left[\because \frac{dq}{dt} = I\right]$$
$$\Rightarrow \quad \frac{dV}{dt} = \frac{I}{C} = \frac{0.15}{8.01\times10^{-12}}$$
$$= 18.7\times10^9\text{ V/s}$$

Thus, the rate of change of potential is 18.7×10^9 V/s.

(ii) The displacement current is equal to the conduction current, i.e. $I_d = 0.15$ A.

(iii) Yes, Kirchhoff's first rule is valid because we take the current to be the sum of conduction current and the displacement current.

50. Given, radius of plates, $R = 6\text{ cm} = 6\times10^{-2}\text{ m}$

Capacitance of capacitor,

$C = 100\text{ pF} = 100\times10^{-12}\text{ F} = 10^{-10}\text{ F}$

Voltage of capacitor, $V = 230$ V

Frequency of capacitor, $\omega = 300$ rad/s

(i) The rms value of current, $I_{\text{rms}} = \frac{V_{\text{rms}}}{X_C}$

$$\therefore \quad X_C = \frac{1}{\omega C} = \frac{1}{300\times10^{-10}} = \frac{10^{10}}{300}\,\Omega$$
$$\therefore \quad I_{\text{rms}} = \frac{230\times300}{10^{10}} = 3\times23\times1000\times10^{-10}$$
$$= 69\times10^{-7}$$
$$= 6.9\times10^{-6}\text{A}$$
$$= 6.9\,\mu\text{A}$$

(ii) Yes, the conduction current is equal to displacement current.

(iii) Given, the distance of point from the axis between the plates, $r = 3\text{ cm} = 3\times10^{-2}\text{ m}$

Radius of plates, $R = 6\text{ cm} = 6\times10^{-2}\text{ m}$

The magnetic field at a point between the plates,

$$B = \frac{\mu_0}{2\pi R^2}\cdot r\cdot I_d$$
$$\Rightarrow \quad B = \frac{\mu_0 r}{2\pi R^2}I \qquad [\because I_d = I]$$

If $I = I_0$ is maximum value of current, then

$I = \sqrt{2}I_{\text{rms}}$

$$\therefore \quad B = \frac{\mu_0 r}{2\pi R^2}\sqrt{2}I_{\text{rms}}$$
$$= \frac{4\pi\times10^{-7}\times0.03\times\sqrt{2}\times6.9\times10^{-6}}{2\pi\times0.06\times0.06}$$
$$= 1.63\times10^{-11}\text{ T}$$

51. E and B vectors must be in x and y-directions.

As we know, $\lambda = \frac{c}{\nu} = \frac{3\times10^8}{30\times10^6} = 10$ m

52. For 7.5 MHz band,

Wavelength, $\lambda_1 = \frac{c}{\nu} = \frac{3\times10^8}{7.5\times10^6} = 40$ m

For 12 MHz band,

Wavelength, $\lambda_2 = \frac{c}{\nu} = \frac{3\times10^8}{12\times10^6} = 25$ m

So, wavelength range is from 25 m to 40 m.

53. Magnetic field, $B = B_0\sin\omega t$

Given equation,

$$B = 12\times10^{-8}\sin\,(1.20\times10^7 z - 3.60\times10^{15}t)\text{T}$$

On comparing this equation with standard equation, we get

$$B_0 = 12\times10^{-8}\text{ T}$$

The average intensity of the beam,

$$I_{av} = \frac{B_0^2}{2\mu_0}\cdot c$$
$$= \frac{1}{2}\times\frac{(12\times10^{-8})^2\times3\times10^8}{4\pi\times10^{-7}}$$
$$\Rightarrow \quad I_{av} = 1.71\text{ W/m}^2$$

54. (i) $\therefore$ Intensity, $I = \frac{\text{Power of visible light}}{\text{Area}}$

$$= \frac{100\times(5/100)}{4\pi(1)^2} = 0.4\text{ W/m}^2$$

(ii) $I = \frac{100\times\left(\frac{5}{100}\right)}{4\pi(10)^2} = 4\times10^{-3}\text{ W/m}^2$

55. Given, amplitude of the magnetic field part of harmonic electromagnetic wave,

$$B_0 = 510\text{ nT} = 510\times10^{-9}\text{ T}$$

Speed of light in vacuum, $c = \frac{E_0}{B_0}$

where, E_0 is the amplitude of electric field part of the wave.

$$\Rightarrow \quad 3\times10^8 = \frac{E_0}{510\times10^{-9}}$$

$$\Rightarrow \quad E_0 = 153 \text{ N/C}$$

Thus, the amplitude of the electric field part of wave is 153 N/C.

56. Given, frequency of oscillation, $\nu = 2\times10^{10}$ Hz

Speed of wave, $c = 3\times10^8$ m/s

Electric field amplitude, $E_0 = 48$ V/m

(i) Wavelength of wave,

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

(ii) The amplitude of the oscillating magnetic field,

$$B_0 = \frac{E_0}{c} = \frac{48}{3\times10^8} = 1.6\times10^{-7} \text{ T}$$

(iii) The average energy density of electric field,

$$u_e = \frac{1}{4}\varepsilon_0 E_0^2 \quad \text{...(i)}$$

As, $\quad E_0 = cB_0$

Putting the value of E_0 in Eq. (i), we get

$$u_e = \frac{1}{4}\varepsilon_0 \cdot c^2 B_0^2 \quad \text{...(ii)}$$

Speed of electromagnetic waves, $c = \dfrac{1}{\sqrt{\mu_0\varepsilon_0}}$ **(1)**

Putting the value of c in Eq. (ii), we get

$$u_e = \frac{1}{4}\varepsilon_0 B_0^2 \cdot \frac{1}{\mu_0\varepsilon_0} = \frac{1}{4}\cdot\frac{B_0^2}{\mu_0} = u_b$$

(u_b is average energy density of magnetic field)

Thus, the average energy density of the **E** field equals the average energy density of **B** field.

57. Given, amplitude of an electromagnetic wave, $E_0 = 120$ N/C

Frequency of wave, $\nu = 50 \text{ MHz} = 50\times10^6$ Hz

(i) Speed of light in vacuum,

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

$$B_0 = \frac{E_0}{c} = \frac{120}{3\times10^8} = 40\times10^{-8}$$

$$= 400\times10^{-9} \text{ T} = 400 \text{ nT}$$

Angular frequency of electromagnetic wave,

$$\omega = 2\pi\nu = 2\times3.14\times50\times10^6$$

$$\omega = 3.14\times10^8 \text{ rad/s}$$

Wave number of electromagnetic wave,

$$k = \frac{\omega}{c} = \frac{3.14\times10^8}{3\times10^8} = 1.05 \text{ rad/m}$$

Wavelength of electromagnetic wave,

$$\lambda = \frac{c}{\nu} = \frac{3\times10^8}{50\times10^6} = 6.00 \text{ m}$$

(ii) Expression of electric field, $E = E_0 \sin(kx - \omega t)$

$$E = 120\sin(1.05x - 3.14\times10^8 t)$$

Expression of magnetic field B,

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

$$B = 4\times10^{-7}\sin(1.05x - 3.14\times10^8 t)$$

58. (i) The given equation signifies that the electromagnetic wave is moving along Y-axis and also in negative direction, so it moves in $-\hat{\mathbf{j}}$-direction.

(ii) The electric part of electromagnetic wave in vacuum,

$$E = [3.1\cos\{1.8y + (5.4\times10^6 t)\}]\,\hat{\mathbf{i}}$$

Comparing with standard equation,

$E = E_0\cos(ky + \omega t)$, we get

Angular frequency, $\omega = 5.4\times10^6$ rad/s

Wave number, $k = 1.8$ rad/m

The amplitude of the electric field part of the wave,

$$E_0 = 3.1 \text{ N/C}$$

$$\lambda = \frac{2\pi}{k} = \frac{2\pi}{1.8} = 3.491 \text{ m}$$

$$\Rightarrow \quad \lambda = 3.5 \text{ m}$$

(iii) Angular frequency, $\omega = 2\pi\nu$

$$\nu = \frac{\omega}{2\pi} = \frac{5.4\times10^6\times7}{2\times22} = 0.86\times10^6 \text{ Hz}$$

(iv) As, $c = \dfrac{E_0}{B_0}$

Amplitude of magnetic field,

$$B_0 = \frac{E_0}{c} = \frac{3.1}{3\times10^8} = 1.03\times10^{-8} \text{ T}$$

(v) Expression for the magnetic field part of wave,

$$B = B_0\cos(ky + \omega t)\hat{\mathbf{k}}$$

$$B = 1.03\times10^{-8}\cos(1.8y + 5.4\times10^6 t)\,\hat{\mathbf{k}}$$

59. Given, $\quad \lambda_m T = 0.29$ cm-K

$$\Rightarrow \quad \lambda_m = \frac{0.29}{T} \text{ cm}$$

Let us take, $\lambda_m = 10^{-6} \text{ m} = 10^{-4}$ cm

Required absolute temperature,

$$T = \frac{0.29}{10^{-4}} = 2900 \text{ K}$$

Let us take, $\lambda_m = 5\times10^{-5}$ cm for visible region.

Required absolute temperature,

$$T = \frac{0.29}{5\times10^{-5}} = 5800 \text{ K} = 6000 \text{ K}$$

Hence, we can find the temperature for other parts of the electromagnetic spectrum in the same way. So, these numbers tell us about the temperature ranges for which atomic vibrations can produce these parts of electromagnetic waves.

60. (i) This wavelength (21 cm) corresponds to the radio waves.

(ii) This frequency (1057 MHz) also corresponds to the radio waves (short wavelength).

(iii) As, $T = 2.7$ K

Using the formula, $\lambda_m T = b = 0.29$ cm-K

$$\lambda_m = \frac{0.29}{2.7} \text{cm} = 0.11 \text{ cm}$$

This wavelength corresponds to the microwaves region of the electromagnetic spectrum.

(iv) This wavelength lies in the visible region of the electromagnetic spectrum.

(v) Energy, $E = 14.4 \text{ keV} = 14.4 \times 10^3 \times 1.6 \times 10^{-19}$ J

Frequency of wave,

$$\nu = \frac{E}{h} = \frac{14.4 \times 1.6 \times 10^{-16}}{6.6 \times 10^{-34}}$$

$$= 3.5 \times 10^{18} \text{ Hz}$$

This frequency lies in the X-ray region of the electromagnetic spectrum.

61. Given, energy of photon, $E = h\nu$

For γ-rays

Frequency of γ-rays, $\nu = 3 \times 10^{20}$ Hz

Energy of γ-rays, $E = h\nu = 6.6 \times 10^{-34} \times 3 \times 10^{20}$

$$= 19.8 \times 10^{-14} \text{ J}$$

$$\Rightarrow \quad E = \frac{19.8 \times 10^{-14}}{1.6 \times 10^{-19}} = 1.24 \times 10^6 \text{ eV}$$

The source of γ-rays is nuclear origin.

For X-rays

Frequency of X-rays, $\nu = 3 \times 10^{18}$ Hz

Energy of X-rays, $E = h\nu = 6.6 \times 10^{-34} \times 3 \times 10^{18}$

$$= 19.8 \times 10^{-16} \text{ J}$$

$$\Rightarrow \quad E = \frac{19.8 \times 10^{-16}}{1.6 \times 10^{-19}}$$

$$= 1.24 \times 10^4 \text{ eV}$$

The retardation of high energy electron produces X-rays. Similarly, we can find for ultraviolet rays, visible rays, infrared rays, microwaves and radio waves.

They originate by oscillating current.

Types of radiation	Photon energy
γ-rays	1.24×10^6 eV
X-rays	1.24×10^4 eV
Ultraviolet rays	4.12 eV
Visible rays	2.475 eV
Infrared waves	4.125×10^{-2} eV
Microwaves	4.125×10^{-5} eV
Radio waves	1.24×10^{-6} eV

SUMMARY

- **Displacement Current** When a capacitor is charged, then electric field is produced due to flow of current inside it. This current is called displacement current. It is given by
$I_d = \frac{\varepsilon_0 \, d\phi_E}{dt}$
- **Basic Idea of Displacement Current** Ampere's circuital law for conduction current during a charging of capacitor was found to be inconsistent. Therefore, Maxwell modified Ampere's circuital by introducing displacement current.
- **Maxwell's Equations** Maxwell's equations are the basic laws of electricity and magnetism.
- **Gauss's Law in Electrostatics** The total electric flux through any closed surface is always equal to $\frac{1}{\varepsilon_0}$ times the net charge enclosed by the surface, i.e. $\oint_S \mathbf{E} \cdot d\,\mathbf{S} = \frac{q}{\varepsilon_0}$.
- **Gauss's Law in Magnetostatics** The net magnetic flux through any closed surface is always zero.
- **Faraday's Law of EMI** The induced emf produced in a circuit is numerically equal to the rate of change of magnetic flux through it.

  i.e. $\oint \mathbf{E} \cdot d\,\mathbf{l} = \frac{-d\phi_B}{dt}$
- **Ampere's-Maxwell Circuital Law** The line integral of the magnetic field along a closed path is equal to μ_0 times the total current threading the surface bounded by that closed path, i.e.
$$\oint \mathbf{B} \cdot d\,\mathbf{l} = \mu(I_c + I_d)$$
- **Electromagnetic Waves** These waves produced due to change in electric field and magnetic field sinusoidally and propagates through space such that the two fields are perpendicular to each other and also to the direction of wave propagation.
- **Source of EM Waves** Accelerating charges produces EM waves.
- **Transverse Nature of EM Waves** Since, the electric and magnetic fields in an electromagnetic wave are perpendicular to each other and also to the direction of wave propagation. Hence, electromagnetic waves are transverse in nature.
- **Electromagnetic Spectrum** The orderly arrangement of EM wave in increasing or decreasing order of wavelength of frequency is called electromagnetic spectrum. The range varies from 10^{-12} m to 10^4 m, i.e. from γ-rays to radiowaves.

CHAPTER PRACTICE (UNSOLVED)

OBJECTIVE Type Questions

1. Out of the following options which one can be used to produce a propagating electromagnetic wave?
(a) A stationary charge
(b) A charge less particle
(c) An accelerating charge
(d) A charge moving at constant velocity

2. If **E** and **B** represent electric and magnetic field vectors of the electromagnetic wave, the direction of propagation of electromagnetic wave is along **NCERT Exemplar**
(a) **E** (b) **B**
(c) **B** × **E** (d) **E** × **B**

3. The range of wavelength of the visible light is
(a) 10 Å to 100 Å (b) 4000 Å to 8000 Å
(c) 8000 Å to 10000 Å (d) 10000 Å to 15000 Å

4. If ε_0 and μ_0 are the electric permittivity and magnetic permeability of free space and ε and μ are the corresponding quantities in the medium, the index of refraction of the medium in terms of above parameter is
(a) $\dfrac{\varepsilon\mu}{\varepsilon_0\mu_0}$ (b) $\left(\dfrac{\varepsilon\mu}{\varepsilon_0\mu_0}\right)^{1/2}$
(c) $\left(\dfrac{\varepsilon_0\mu_0}{\varepsilon\mu}\right)$ (d) $\left(\dfrac{\varepsilon_0\mu_0}{\varepsilon\mu}\right)^{1/2}$

5. The ratio of contributions made by the electric field and magnetic field components to the intensity of an EM wave is **NCERT Exemplar**
(a) $c:1$ (b) $c^2:1$
(c) 1 : 1 (d) $\sqrt{c}:1$

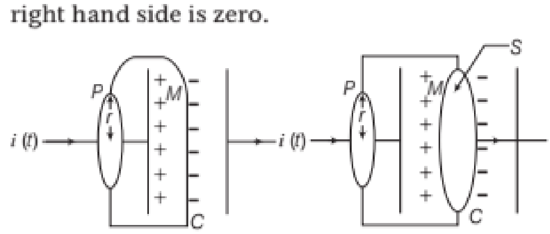
6. Frequency of wave is 6×10^{10} Hz. The wave is
(a) radiowave (b) microwave
(c) X-ray (d) None of these

7. In the following waves, which is not electromagnetic wave?
(a) α-rays (b) γ-rays
(c) Infrared rays (d) X-rays

8. The largest wavelength of electromagnetic wave is
(a) X-rays (b) radio waves
(c) ultraviolet rays (d) infrared rays

Directions (Q. Nos. 9-12) *In the following questions, two statements are given- one labeled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.*
(a) Both Assertion and Reason are true and Reason is the correct explanation of Assertion.
(b) Both Assertion and Reason are true but Reason is not the correct explanation of Assertion.
(c) Assertion is true but Reason is false.
(d) Assertion is false but Reason is true.

9. Assertion While applying Ampere's circuital law to given surfaces with same perimeter, the left hand side $\oint B \cdot dl = \mu_0 i(t)$ has not changed but the right hand side is zero.



Reason No current passes through the surface.

10. Assertion We needed to do was to set up an AC circuit in which the current oscillate at the frequency of visible light *i.e.,* yellow.

Reason The above experiment demonstrates electromagnetic wave.

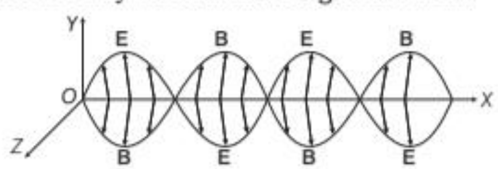
11. **Assertion** An oscillating charge produces an electric field in space, which produces an oscillating magnetic field, which in turn, is a source of electric field and so on.
Reason The oscillating electric and magnetic field thus regenerate each other, so to speak, as the wave propagates through the space.

12. **Assertion** When the sun shines on our hand, we feel the energy being absorbed from the electromagnetic waves (our hands get warm).
Reason Electromagnetic waves also transfer momentum to our hand but because c is very large, the amount of momentum transferred is extremely small and we do not feel the pressure.

Directions (Q.No. 13) *This question is case study based question. Attempt any 4 sub-parts from this question. Each question carries 1 mark.*

13. **EM Wave**

Electromagnetic waves are transverse in nature. *i.e.*, electric and magnetic fields are perpendicular to each other and to the direction of wave propagation. Electromagnetic waves are not deflected by electric and magnetic fields.



The magnetic field in a plane electromagnetic wave is given by
$B_y = 2\times10^{-7}\sin(0.5\times10^3 x + 1.5\times10^{11}t)$T.

(i) What is the angular frequency of wave?
(a) 0.5×10^3 rad s^{-1}
(b) 1.5×10^{11} rad s^{-1}
(c) 3×10^8 rad s^{-1}
(d) 2×10^{-7} rad s^{-1}

(ii) What is the wavelength of the wave?
(a) 12.6 cm (b) 1.26 cm
(c) 1. 26 m (d) 6.12 m

(iii) What is the frequency of the wave?
(a) 2.39 GHz (b) 23.9 MHz
(c) 23.9 GHz (d) 20.3 MHz

(iv) The maximum value of electric field is
(a) 6×10^2 Vm^{-1}
(b) 6×10^3 Vm^{-1}
(c) 6×10^1 Vm^{-1}
(d) 6 Vm^{-1}

(v) Write an expression for the electric field?
(a) $E_y = 60\sin(0.5\times10^3 x + 1.5\times10^{11} t)$ Vm^{-1}
(b) $E_x = 60\sin(0.5\times10^3 x + 1.5\times10^{11} t)$ Vm^{-1}
(c) $E_z = 60\sin(0.5\times10^3 x + 1.5\times10^{11} t)$ Vm^{-1}
(d) $E_y = 60\cos(0.5\times10^3 x + 1.5\times10^{11} t)$ Vm^{-1}

VERY SHORT ANSWER Type Questions

14. Depict the fields diagram of an electromagnetic wave propagating along positive X-axis with its electric field along Y-axis.

15. A capacitor is attached to a variable frequency of an AC source. What will happen to the displacement current with the increase in frequency?

16. To which part of electromagnetic spectrum do the waves emitted by radioactive nuclei belong? What is its frequency range?

17. Which part of the electromagnetic spectrum is used in radar? Give its frequency range.

Or How are electromagnetic waves produced by accelerating charges?

18. Write two uses of infrared rays.

19. Give the ratio of velocity of the two light waves of wavelengths 4000Å and 8000Å travelling in vacuum.

20. Mention one use of part of electromagnetic spectrum to which a wavelength of 21 cm (emitted by hydrogen in interstellar space) belongs.

21. What is common between difference types of electromagnetic radiations?

22. A laser beam has an intensity of 4×10^{14} W/m^2. What will the amplitude of electric field in the beam?

SHORT ANSWER Type Questions

23. When a plane electromagnetic wave travels in vacuum along y-direction. Write the
(i) ratio of the magnitudes and
(ii) the direction of its electric and magnetic field vectors.

24. How are electromagnetic waves produced by oscillating charges? What is the source of the energy associated with the EM waves?

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

26. A radio can tune into any station from 5.5 MHz to 16 MHz band. What is the corresponding wavelength band?

27. Green light of mercury has a wavelength 5×10^{-5} cm.

(i) What is the frequency in MHz and period in second in vacuum?

(ii) What is the wavelength in glass, if refractive index of glass is 1.5?

28. Name the electromagnetic radiation to which waves of wavelength in the range of 10^{-2}m belong. Give one use of this part of electromagnetic spectrum.

29. Find the wavelength of electromagnetic wave of frequency 5×10^{10}Hz in free space. Give its two applications.

LONG ANSWER Type I Questions

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

(b) Prove that the average energy density of the oscillating electric field is equal to that of the oscillating magnetic field.

31. (a) We feel the warmth of the sunlight but not the pressure on our hands. Explain.

(b) Which out of wavelength, frequency and speed of an electro-magnetic wave does not change on passing from one medium to another?

(c) A thin ozone layer in the upper atmosphere is crucial for human survival on earth, why?

32. (a) How are electromagnetic waves produced? Depict an electromagnetic wave propagation in z-direction with its magnetic field **B** oscillating along x-direction.

(b) Write two characteristics of electromagnetic waves.

33. Name the constituent radiation of electromagnetic spectrum which

(i) is used in satellite communication.

(ii) is used for studying crystal structure.

(iii) is emitted during decay of radioactive nuclei.

Write two more uses of each.

34. How are X-rays different from γ-rays? Give a detailed description.

ANSWERS

1. (*c*) **2.** (*d*) **3.** (*b*) **4.** (*b*) **5.** (*c*)

6. (*b*) **7.** (*a*) **8.** (*b*)

9. (*a*) On applying Ampere's circuital law to such surfaces with the same perimeter, we find that the left hand side of equation $\oint B.dl = \mu_0 i(t)$ has not changed but the right hand side is zero and not $\mu_0 i$. Since, no current passes through the surface.

10. (*c*) We needed to set up an AC circuit in which the current oscillate at the frequency of visible light, *i.e.*, yellow. The frequency of yellow light is about 6×10^{14} Hz, while the frequency that we get even with modern electronic circuits is hardly about 10^{11} Hz. This is why the experimental demonstration of electromagnetic wave had to come in the low frequency region (the radio wave region), as in the Hertz's experiment (1887).

11. (*a*) An oscillating charge produces an electric field in space, which produces an oscillating magnetic field, which in turn, is a source of electric field.

12. (*a*) When the sun shines on your hand, you feel the energy being absorbed from the electromagnetic waves (your hands get warm). Electromagnetic waves also transfer momentum to your hand but because c is very large, the amount of momentum transferred is extremely small and you do not feel the pressure.

13. (i) (*b*) Comparing with given equation, we get

$$\omega = 1.5 \times 10^{11} \text{ rad s}^{-1}$$

(ii) (*b*) Comparing the given equation with magnetic field in a plane

i.e., $$B_y = B_0 \sin\left[2\pi\left(\frac{x}{\lambda} + \frac{t}{T}\right)\right]$$

we get $$\lambda = \frac{2\pi}{0.5 \times 10^3} \text{ m} = 1.26 \text{ cm}$$

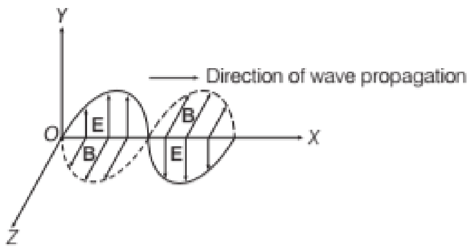
(iii) (*c*) As we know, frequency *i.e.*, $\nu = \dfrac{1}{\text{Time taken}}$

$$\nu = \frac{1}{T} = \frac{\omega}{2\pi} = (1.5 \times 10^{11}) \ / \ 2\pi = 23.9 \text{ GHz}$$

(iv) (*c*) According to Maxwell equation, electric field *i.e.*, $E_0 = B_0 c = 2 \times 10^{-7} \times 3 \times 10^8 \text{ ms}^{-1} = 6 \times 10^1 \text{ Vm}^{-1}$

(v) (*c*) The electric field component is perpendicular to the direction of propagation and the direction of magnetic field. Therefore, the electric field component along the Z-axis is obtained as $E_z = 60 \sin(0.5 \times 10^3 x + 1.5 \times 10^{11} t) \text{ Vm}^{-1}$

14. An electromagnetic wave propagating along positive X-axis with its electric field Y-axis, will have its magnetic field along Z-axis, as shown below



15. When frequency of AC source increases, then displacement current also increases.

16. Gamma rays, its frequency range is 3×10^{18} Hz to 5×10^{22} Hz.

17. Microwaves are used in radar systems of aircraft navigation. Its frequency range is 1 GHz to 300 GHz.

Or

Refer to text on page 330.
(Source of Electromagnetic Waves)

18. Two uses of infrared rays are
(i) in weather forecasting.
(ii) in production of dehydrated fruits.

19. As, light waves travel in free space or vacuum with the speed of light (3×10^8 ms^{-1}), irrespective of their wavelengths. So, the ratio of velocity of given light waves is 1 : 1.

20. Given, wavelength, $\lambda = 21$ cm $= 0.21$ m

The range of the wavelength of microwaves is approximately 30 cm to 1 mm. Thus, the given wavelength emitted by hydrogen interstellar space belongs to microwaves. These are used in RADAR systems for aircraft navigation.

21. Speed, in vacuum all types of electromagnetic wave travels with same speed, i.e. 3×10^8 m/s.

22. We know that, $E_0 = \sqrt{\dfrac{2I}{\varepsilon_0 c}}$

$$= \sqrt{\frac{2 \times 4 \times 10^{14}}{8.85 \times 10^{-12} \times 3 \times 10^8}}$$

$$= 5.489 \times 10^8 \text{ N/C}$$

23. Refer to text on pages 330 and 331.

24. Refer to text on page 330.
(Source of Electromagnetic Waves)

25. Refer to text on pages 332 and 333.

26. Here, $\nu_1 = 5.5$ MHz $= 5.5 \times 10^6$ Hz

$$\nu_2 = 16 \text{ MHz} = 16 \times 10^6 \text{ Hz}$$

$$\therefore \quad \lambda_1 = \frac{c}{\nu_1} = \frac{3 \times 10^8}{5.5 \times 10^6}$$

$$= 0.545 \times 10^2 \text{ m} = 54.5 \text{ m}$$

$$\Rightarrow \quad \lambda_2 = \frac{c}{\nu_2} = \frac{3 \times 10^8}{16 \times 10^6} = 0.1875 \times 10^2$$

$$= 18.75 \text{ cm}$$

Hence, corresponding wavelengths of above frequencies are 54.5 m and 18.75 m.

27. (i) Frequency of the wave, $\nu = \dfrac{c}{\lambda} = \dfrac{3 \times 10^8 \text{ m/s}}{5 \times 10^{-5} \text{ cm}}$

$$= \frac{3 \times 10^8 \text{ m/s}}{5 \times 10^{-7} \text{ m/s}} = 6 \times 10^{14} \text{ Hz}$$

$$\text{Time period, } T = \frac{1}{\nu} = \frac{1}{6 \times 10^{14} \text{ Hz}} = 0.16 \times 10^{-14} \text{ s}$$

(ii) Refractive index, $\mu = \dfrac{c}{v}$

$$\Rightarrow \quad v = \frac{c}{\mu} = \frac{3 \times 10^8}{1.5} = 2 \times 10^8 \text{ m/s}$$

Also, $\nu = \dfrac{v}{\lambda}$

$$\Rightarrow \quad \lambda = \frac{v}{\nu} = \frac{2 \times 10^8}{6 \times 10^{14}} = 0.33 \times 10^{-6} \text{ m}$$

$$= 3.3 \times 10^{-3} \text{ m}$$

28. Refer to text on page 332.

29. Refer to text on pages 332 and 333.

30. (a) (i) Microwave - 1 GHz to 300 GHz.
(ii) Ultraviolet (by LASIK eye surgery) -10^{14} Hz to 10^{16} Hz.
(b) Refer to text on page 331 [Important Characteristics of Electromagnetic
Waves (vii)]

31. Refer to text on pages 332 and 333.

32. Refer to text on page 331.

33. Refer to text on pages 332 and 333.

34. Refer to text on page 333.