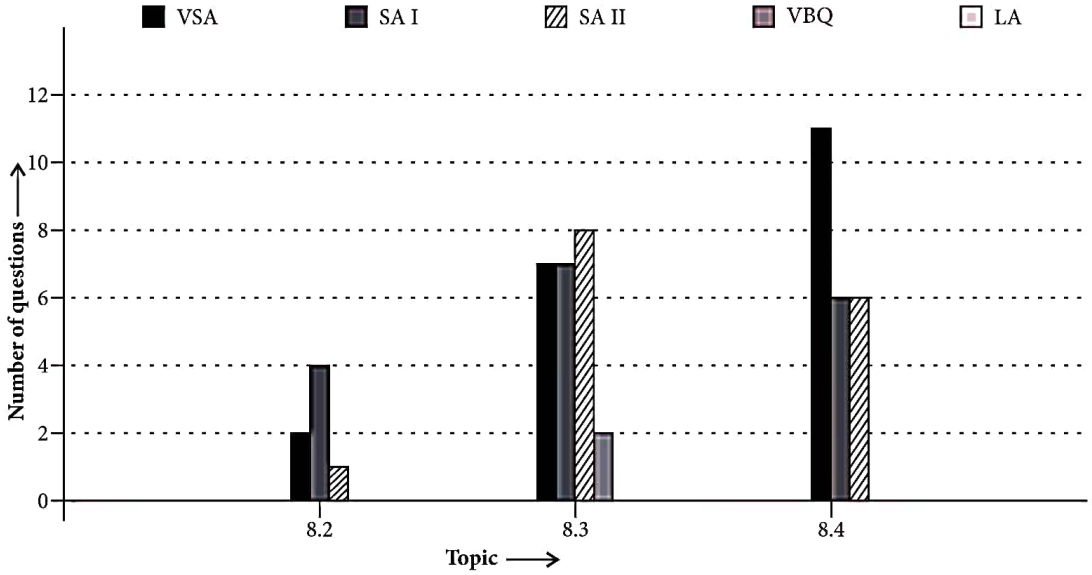
08 Electromagnetic Waves

8.2 Displacement Current
8.3 Electromagnetic Waves
8.4 Electromagnetic Spectrum

Topicwise Analysis of Last 10 Years' CBSE Board Questions



- Maximum weightage is of *Electromagnetic Waves.*
- Maximum VSA type questions were asked from *Electromagnetic Spectrum.*
- Maximum SA I and SA II type questions were asked from *Electromagnetic Waves.*
- No LA type questions were asked till now.

QUICK RECAP

Displacement Current : The current which comes into play in the region, wherever the electric field and hence the electric flux is changing with time. It is given by

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

where ε_0 is the permittivity of free space and $\frac{d\phi_E}{dt}$ is the rate of change of electric flux.

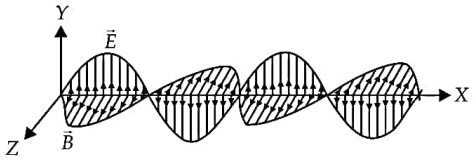
- Ampere's circuital law for conduction current during charging of a capacitor was found inconsistent. Therefore, Maxwell modified Ampere's circuital law.

Maxwell's equations : The basic principle of electromagnetism can be formulated in terms of four fundamental equations known as Maxwell's equations.

- Maxwell's equations are :
  - Gauss's Law for electrostatics
    $$\oint \vec{E} \cdot d\vec{S} = \frac{q}{\varepsilon_0}$$
  - Gauss's Law for magnetism
    $$\oint \vec{B} \cdot d\vec{S} = 0$$
  - Faraday's Law of electromagnetic induction
    $$\oint \vec{E} \cdot d\vec{l} = -\frac{d\phi_B}{dt}$$
  - Maxwell-Ampere's circuital Law
    $$\oint \vec{B} \cdot d\vec{l} = \mu_0 \left[I + \varepsilon_0 \frac{d\phi_E}{dt} \right]$$

Electromagnetic waves : E.M. waves are those waves in which there is a sinusoidal variation of electric and magnetic field at right angles to each other as well as at right angles to the direction of wave propagation.

- For a plane progressive electromagnetic wave propagating along + z direction, the electric and magnetic fields can be written as
  $E = E_0 \sin(kz - \omega t)$
  $B = B_0 \sin(kz - \omega t)$



- In electromagnetic wave, the electric and magnetic fields vary with space and time and have the same frequency and are in the same phase.
- The amplitudes of electric and magnetic fields in free space, in electromagnetic waves are related by
  $$E_0 = cB_0 \quad \text{or} \quad B_0 = \frac{E_0}{c}$$
- The speed of electromagnetic wave in free space is
  $$c = \frac{E_0}{B_0} = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3 \times 10^8 \text{ m/s}$$
  where μ_0 and ε_0 are the permeability and permittivity of free space respectively.
- The speed of electromagnetic wave in a medium is
  $$v = \frac{1}{\sqrt{\mu\varepsilon}}$$
  where μ and ε are permeability and permittivity of the medium respectively.
  $$v = \frac{1}{\sqrt{\mu_0 \mu_r \varepsilon_0 \varepsilon_r}} = \frac{c}{\sqrt{\mu_r \varepsilon_r}}$$
- **Properties of electromagnetic waves**
  - These waves do not carry any charge.
  - These waves are not deflected by electric and magnetic fields.
  - They travel with the speed of light c ($= 3 \times 10^8$ ms^{-1}) in vacuum.
  - The frequency of electromagnetic wave does not change when it goes from one medium to another but its wavelength changes.
  - These waves are transverse in nature, hence they can be polarised.
- **Production of electromagnetic waves**
  - Maxwell showed that an electric charge oscillating harmonically with frequency υ produces electromagnetic waves of the same frequency.
  - An electric dipole is a basic source of electromagnetic waves.
- **Energy density of electromagnetic waves**
  - Electromagnetic waves carry energy as they travel through space and this energy is equally shared by electric field and magnetic field of electromagnetic wave.
  - The energy density of the electric field is
    $$u_E = \frac{1}{2} \varepsilon_0 E_{rms}^2$$
  - The energy density of magnetic field is
    $$u_B = \frac{1}{2} \frac{B_{rms}^2}{\mu_0}$$
  - Average energy density of electromagnetic wave is
    $$< u > = \frac{1}{2} \varepsilon_0 E_{rms}^2 + \frac{1}{2\mu_0} B_{rms}^2$$
- **Intensity of electromagnetic wave :** It is defined as energy crossing per unit area per unit time perpendicular to the direction of propagation

of electromagnetic wave. The intensity of electromagnetic wave is

$$I = < u > c = \frac{1}{2} \varepsilon_0 E_{rms}^2 c$$

▶ **Momentum of electromagnetic wave**

- An electromagnetic wave carries linear momentum.
- Electromagnetic wave strikes the surface at normal incidence and transports a total energy U to the surface in a time t, if the surface absorbs all the incident energy, the total momentum p transported to the surface is

$$p = \frac{U}{c} \text{ (complete absorption)}$$

- If the surface is a perfect reflector and incidence is normal then the momentum transported to the surface is

$$p = \frac{2U}{c} \text{ (complete reflection)}$$

Radiation pressure : It is defined as the pressure exerted by the electromagnetic wave on a surface.

▶ If I is the intensity of the incident electromagnetic radiation, then the radiation pressure for normal incidence is

$$P_{\text{radiation}} = \frac{I}{c} \text{ (perfectly absorbing surface)}$$

$$P_{\text{radiation}} = \frac{2I}{c} \text{ (perfectly reflecting surface)}$$

Electromagnetic spectrum : The orderly distribution of electromagnetic radiations according to their wavelength or frequency is known as electromagnetic spectrum.

Type	Wavelength range	Frequency range (in Hz)	Production	Detection
Radio waves	> 0.1 m	$< 3 \times 10^9$	Rapid acceleration and deceleration of electrons in aerials	Receiver's aerials
Microwaves	0.1 m to 1 mm	3×10^8 to 3×10^{11}	Klystron valve or magnetron valve	Point contact diodes
Infra-red	1 mm to 700 nm	3×10^{11} to 4×10^{14}	Vibration of atoms and molecules	Thermopiles, Bolometer, Infrared photographic film
Visible light	700 nm to 400 nm	4×10^{14} to 8×10^{14}	Electrons in atoms emit light when they move from one energy level to a lower energy level	The eye, Photocells, Photographic film
Ultraviolet	400 nm to 1 nm	8×10^{14} to 8×10^{16}	Inner shell electrons in atoms moving from one energy level to a lower level	Photocells, Photographic film
X-rays	1 nm to 10^{-3} nm	1×10^{16} to 3×10^{21}	X-ray tubes or inner shell electrons	Photographic film, Geiger tubes
Gamma rays	$< 10^{-3}$ nm	$> 3 \times 10^{21}$	Radioactive decay of the nucleus	Photographic film, Ionization chamber

Previous Years' CBSE Board Questions

8.2 Displacement Current

VSA (1 mark)

1. The charging current for a capacitor is 0.25 A. What is the displacement current across its plates? *(Foreign 2016)*
2. 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)*

SA I (2 marks)

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

   (b) How are the magnitudes of the electric and magnetic fields related to velocity of the *e.m.* wave? *(Delhi 2013)*
4. A capacitor, made of two parallel plates each of plate area 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. *(AI 2013)*
5. 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)*
6. 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. *(AI 2012)*

SA II (3 marks)

7. Write the expression for the generalized 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. *(AI 2015)*

8.3 Electromagnetic waves

VSA (1 mark)

8. Why are microwaves considered suitable for radar systems used in aircraft navigation? *(Delhi 2016)*
9. 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. *(AI 2013)*
10. Name the physical quantity which remains same for microwaves of wavelength 1 mm and UV radiations of 1600 Å in vacuum. *(Delhi 2012)*
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? *(AI 2012)*
12. What is the frequency of electromagnetic waves produced by oscillating charge of frequency v? *(Delhi 2011C)*
13. In what ways are the directions of the electric and magnetic field vectors representing an electromagnetic wave related to each other? *(Delhi 2010C)*
14. Express the velocity of propagation of an *e.m.* wave in terms of the peak value of the electric and magnetic fields.

SA I (2 marks)

15. Name the types of *e.m.* radiations which (i) are used in destroying cancer cells, (ii) cause

tanning of the skin and (iii) maintain the earth's warmth.

Write briefly a method of producing any one of these waves. *(AI 2015C)*

16. Answer the following questions:
(i) Show, by giving a simple example, how *e.m.* waves carry energy and momentum.
(ii) How are microwaves produced? Why is it necessary in microwave ovens to select the frequency of microwaves to match the resonant frequency of water molecules?
(iii) Write two important uses of infrared waves. *(Delhi 2014C)*

17. (a) How are electromagnetic waves produced?
(b) How do you convince yourself that electromagnetic waves carry energy and momentum? *(Delhi 2013C)*

18. Explain briefly how electromagnetic waves are produced by an oscillating charge. How is the frequency of the *e.m.* waves produced related to that of the oscillating charge? *(Foreign 2012)*

19. Draw a sketch of a plane electromagnetic wave propagating along the z-direction. Depict clearly the directions of electric and magnetic fields varying sinusoidally with z. *(AI 2010)*

20. How are X-rays produced? Write their two important uses. *(Foreign 2010)*

21. The oscillating magnetic field in a plane electromagnetic wave is given by

$B_y = (8 \times 10^{-6}) \sin [2 \times 10^{11} t + 300 \pi x]$T

(i) Calculate the wavelength of the electromagnetic wave.
(ii) Write down the expression for the oscillating electric field.

SA II (3 marks)

22. Write Maxwell's generalization of Ampere's Circuital Law. Show that in the process of charging a capacitor, the current produced within the plates of the capacitor is

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

where ϕ_E is the electric flux produced during charging of the capacitor plates. *(Delhi 2016)*

23. How are *e.m.* waves produced by oscillating charges ?
Draw a sketch of linearly polarized e.m. waves propagating in the z-direction. Indicate the directions of the oscillating electric and magnetic fields. *(Delhi 2016)*

24. (i) Identify the part of the electromagnetic spectrum which is:
(a) suitable for radar system used in aircraft navigation,
(b) produced by bombarding a metal target by high speed electrons.
(ii) Why does a galvanometer show a momentary deflection at the time of charging or discharging a capacitor ? Write the necessary expression to explain this observation. *(AI 2016)*

25. Answer the following questions:
(a) Name the *e.m.* waves which are suitable for radar systems used in aircraft navigation. Write the range of frequency of these waves.
(b) If the Earth did not have atmosphere, would its average surface temperature be higher or lower than what it is now? Explain.
(c) An e.m. wave exerts pressure on the surface on which it is incident. Justify. *(Delhi 2014)*

26 How are electromagnetic waves produced by oscillating charges? *(1/3, Foreign 2013)*

27. (a) When the oscillating electric and magnetic fields are along the x-and y-direction respectively.
(i) point out the direction of propagation of electromagnetic wave.
(ii) express the velocity of propagation in terms of the amplitudes of the oscillating electric and magnetic fields.
(b) How do you show that the e.m. wave carries energy and momentum? *(AI 2013C)*

28. How does an oscillating charge produce electromagnetic wave? Explain.

Draw a sketch showing the propagation of plane *e.m.* wave along the Z-direction, clearly depicting the directions of oscillating electric and magnetic field vectors. *(Foreign 2014, Delhi 2012C)*

29. Describe briefly how electromagnetic waves are produced by oscillating charges.
(1/3, AI 2011C)

VBQ (4 marks)

30. For the past some time, Aarti had been observing some erratic body movement, unsteadiness and lack of coordination in the activities of her sister Radha, who also used to complain of severe headache occassionally. Aarti suggested to her parents to get a medical check-up of Radha. The doctor thoroughly examined Radha and diagnosed that she has a brain tumour.
(a) What, according to you, are the values displayed by Aarti?
(b) How can radioisotopes help a doctor to diagnose brain tumour?
(3 marks, AI 2014)

31. Anuj's mother was having a constant headache and was diagoned with tumor. She was avoiding treatment because of financial constraints. When Anuj learnt about it, he cancelled his plans to go abroad and decided to use that money for the treatment and care of his mother. Answer the following questions :
(a) What, according to you, are the values displayed by Anuj?
(b) Which type of radiation do you think could be used for the treatment?
(c) Why are γ-rays emitted by a nucleus ?
(AI 2013C)

8.4 Electromagnetic spectrum

VSA (1 mark)

32. To which part of the electromagnetic spectrum does a wave of frequency 5×10^{19} Hz belong?
(AI 2014)

33. Arrange the following electromagnetic waves in order of increasing frequency :
γ-rays, Microwaves, Infrared rays and Ultraviolet rays. *(Foreign 2014)*

34. Name the electromagnetic waves, which (i) maintain the Earth's warmth and (ii) are used in aircraft navigation. *(Foreign 2012)*

35. A plane electromagnetic wave travels in vacuum along z-direction. What can you say about the direction of electric and magnetic field vectors?
(Delhi 2011)

36. How are radio waves produced? *(AI 2011)*

37. Write two uses of microwaves. *(Foreign 2011)*

38. Which part of electromagnetic spectrum has largest penetrating power? *(Delhi 2010)*

39. Name the part of electromagnetic spectrum whose wavelength lies in the range of 10^{-10} m. Give its one use. *(AI 2010)*

40. Which part of the electromagnetic spectrum is used in satellite communication?
(Foreign 2010)

41. Write the following radiations in ascending order in respect of their frequencies :
X-rays, Microwaves, UV rays and Radio waves.
(Delhi 2009)

42. Name the part of the electromagnetic spectrum of wavelength 10^{-2} m and mention its one application.

SA I (2 marks)

43. Arrange the following electromagnetic waves in the descending order of their wavelengths :
(i) Microwaves
(ii) Infra-red rays
(iii) Ultra-violet-radiation
(iv) Gamma rays
(b) Write one use each of any two of them.
(Delhi 2013C)

44. How are infrared waves produced? Why are these referred as heat waves? Write their one important use? *(Delhi 2011)*

45. Name the constituent radiation of electromagnetic spectrum which is used for
(i) aircraft navigation.
(ii) studying crystal structure.
Write the frequency range for each.
(Delhi 2011C)

46. Arrange the following electromagnetic radiations in ascending order of their frequencies :
(i) Microwave (ii) Radiowave
(iii) X-rays (iv) Gamma rays
(Delhi 2010)

47. Name one method each for the (i) production and (ii) detection of X-rays. *(Delhi 2010C)*

48. Write one method each of (i) production, and (ii) detection of microwaves. *(AI 2010C)*

SA II (3 marks)

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

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

(Foreign 2016)

50. Name the parts of the electromagnetic spectrum which is

(a) suitable for radar systems used in aircraft navigation.

(b) used to treat muscular strain.

(c) used as a diagnostic tool in medicine.

Write in brief, how these waves can be produced. *(Delhi 2015)*

51. State clearly how a microwave oven works to heat up a food item containing water molecules.

Why are microwaves found useful for the radar systems in aircraft navigation?

(2/3, Foreign 2013)

52. Give one use of each of the following :

(i) Microwaves

(ii) Ultraviolet rays

(iii) Infra-red rays

(iv) Gamma rays *(2/3, AI 2011C)*

53. Write any four characteristics of electromagnetic waves. Give two uses each of (i) Radio-waves (ii) Micro-waves. *(Delhi 2007)*

54. 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. *(AI 2007)*

Detailed Solutions

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

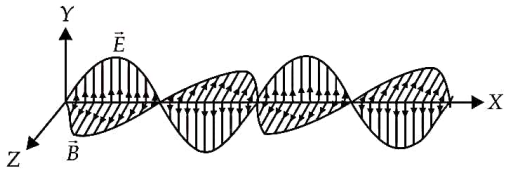
2. Electric flux through plates of capacitor, $\phi_E = \frac{q}{\varepsilon_0}$

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, $I = C\frac{dV}{dt} = 0$ as voltage becomes constant.

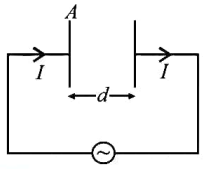
So, $I = I_D = 0$ for a charged capacitor.

3. (a) In figure the velocity of propagation of *e.m.* wave is along X-axis $\vec{v} = v\hat{i}$ and electric field $\vec{E}$ along Y-axis and magnetic field $\vec{B}$ along Z-axis.



(b) Speed of *e.m.* wave can be given as the ratio of amplitude of magnitude of electric field $(\vec{E}_0)$ to the magnitude of magnetic field $(\vec{B}_0)$, *i.e.*, $c = \frac{E_0}{B_0}$

4.



The displacement current within capacitor plates

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

where $\phi_E = EA = \frac{q}{A\varepsilon_0}A = \frac{q}{\varepsilon_0}$

So, $I_d = \frac{\varepsilon_0}{\varepsilon_0}\frac{dq}{dt}$

$I_d = I$

5. When an ideal capacitor is charged by dc battery, charge flows till the capacitor gets fully charged. When an ac source is connected then conduction current $I_c = \frac{dQ}{dt}$ flows in the connecting wire. Due to charging current, charge deposited on the plates of the capacitor changes with time. Changing charge causes electric field between the plates of capacitor to be varying, giving rise to displacement current $I_d = \varepsilon_0 \frac{d\phi_E}{dt}$. [As displacement current is proportional to the rate of flux variation].

The electric field between the plates is

$$E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{A\varepsilon_0}$$

Electric flux, $\phi_E = EA = \frac{Q}{A\varepsilon_0}A = \frac{Q}{\varepsilon_0}$

So, $I_d = \varepsilon_0 \frac{d\phi_E}{dt} = \varepsilon_0 \frac{d}{dt}\left(\frac{Q}{\varepsilon_0}\right) = \frac{dQ}{dt} = I_c$

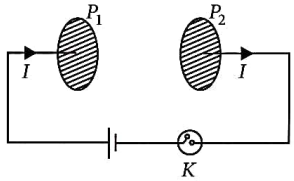
Displacement current brings continuity in the flow of current between the plates of the capacitor.

6. Yes, ammeter will show a momentary deflection.The momentary deflection is due to the flow of electrons in the circuit during the charging process. During the charging process the electric field between the capacitor plates is increasing and hence a displacement current flows in the gap. Hence we can say that there is a continuity of current in the circuit.

Expression, $I_d = \varepsilon_0 \frac{d\phi}{dt}$

7. Generalized form of Ampere's circuital law :

$$\oint \vec{B} \cdot d\vec{l} = \mu_0\left(I + \varepsilon_0 \frac{d\phi E}{dt}\right)$$



Inconsistency of Ampere's circuital law

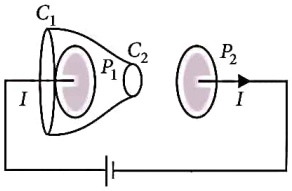
If we observe the current through a charging capacitor, some of the questions arise.

(a) Current I enters at the left end of plate P_1 but no current at right side of plate P_1.

Hence Kirchhoff's law violated.

(b) Ampere's law for loop C_1

$$\int_{C_1} \vec{B} \cdot d\vec{l} = \mu_0 I$$



$I \neq 0$ so $B \neq 0$

For loop C_2,

$$\int_{C_2} \vec{B} \cdot d\vec{l} = \mu_0[0] \qquad (\because I = 0)$$

so $B = 0$.

So, magnetic field reduces 0 on right side from any value on left plate.

But in the actual magnetic field as of continuous nature.

Modified Ampere's law by Maxwell

According to Maxwell,

$$\int \vec{B} \cdot d\vec{l} = \mu_0 (I + I_D) = \mu_0 \left[I + \varepsilon_0 \frac{d\phi_e}{dt} \right]$$

Thus, within the plates the displacement current which is due to changing electric flux in charging/ discharging maintains the continuity of current and magnetic field also within the plates of capacitor.

8. Microwaves have short wavelengths so they are suitable for radar systems used in aircraft navigation. They can penetrate through clouds also.

9. Ultraviolet radiations produced during welding are harmful to eyes. Special goggles or face masks are used to protect eyes from UV radiations. UV radiations have a range of frequency between 10^{14} Hz – 10^{16} Hz.

10. The speed in vacuum (*i.e.* $c = 3 \times 10^8$ m s^{-1}) remains same for both the given wavelengths. It is because both microwaves and UV rays are electromagnetic waves.

11. In an electromagnetic wave $\vec{E}, \vec{B}$ and direction of propagation are mutually perpendicular.

12. Frequency of the electromagnetic wave produced will be equal to the frequency υ of oscillating charge.

13. The electric field $\vec{E}$ and magnetic field $\vec{B}$ are perpendicular to each other.

14. In *e.m.* waves, the ratio of amplitudes of electric and magnetic field is always constant and is equal to the speed of *e.m.* waves. *i.e.*

$c = \frac{E_0}{B_0}$ (where E_0 and B_0 are peak values)

15. (a) (i) Gamma rays

(ii) UV rays

(iii) Infra-red radiations

(b) Infra-red waves are produced by hot bodies and molecules. Infra-red waves are referred to as heat waves, because water molecules present in most materials readily absorb infra-red waves (many other molecules, for example, CO_2, NH_3 also absorb infra-red waves). After absorption, their thermal motion increases, that is they heat up and heat their surroundings.

16. (i) Consider a plane perpendicular to the direction of propagation of the wave. An electric charge, on the plane will be set in motion by the electric and magnetic fields of *e.m.* wave, incident on this plane. This illustrates that *e.m.* waves carry energy and momentum.

(ii) Microwaves are produced by special vacuum tube like the klystron, magnetron and Gunn diode. The frequency of microwaves is selected to match the resonant frequency of water molecules, so that energy is transformed efficiently to the kinetic energy of the molecules.

(iii) Uses of infra-red rays :

1. They are used in night vision devices during warfare. This is because they can pass through haze, fog and mist.
2. Infra-red rays are used in remote switches of household electrical appliances.

17. (a) An oscillating or accelerated charge is supposed to be source of an electromagnetic wave. An oscillating charge produces an oscillating electric field in sapce 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.

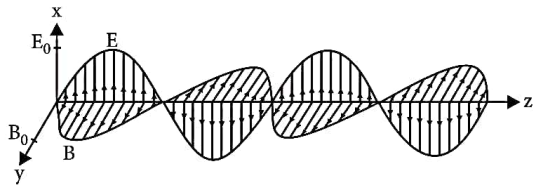
(b) Electromagnetic waves or photons transport energy and momentum. When an electromagnetic wave interacts with a small particle, it can exhange energy and momentum with the particle. The force exerted on the particle is equal to the momentum

transferred per unit time. Optical tweezers use this force to provide a non-invasive technique for manipulating microscopic-sized particles with light.

18. *Refer to answer 17 (a).*

The frequency of *e.m.* wave = Frequency of oscillating charge.

19. An *e.m.* wave propagating along *z*-axis is,



20. Production of X-rays : When high energetic electrons strike a metallic target of high atomic weight and high melting point, X-rays are produced. In production of X-rays mechanical energy of electrons is converted with electromagnetic energy of *X*-rays.

Uses : (i) X-rays are used in medical diagnostics to detect fractures in bones, tuberculosis of lungs, presence of stone in gallbladder and kidney. (ii) They are used in engineering to check flaws in bridges. In physics X-rays are used to study crystal structure.

21. Given equation is

$B_y = (8 \times 10^{-6}) \sin [2 \times 10^{11}\, t + 300\, \pi x]\,\text{T}$

Comparing the given equation with the equation of magnetic field varying sinusoidally with x and t

$$B_y = B_0 \sin\left(\frac{2\pi x}{\lambda} + \frac{2\pi t}{T}\right)$$

We get, $\frac{2\pi}{\lambda} = 300\pi$

$$\therefore \quad \lambda = \frac{2}{300} = 0.0067\,\text{m}$$

and $B_0 = 8 \times 10^{-6}$ T

(i) Wavelength of the electromagnetic wave

$\lambda = 0.0067$ m

(ii) $E_0 = cB_0 = 3 \times 10^8 \times 8 \times 10^{-6}$

$= 24 \times 10^2 = 2400\ \text{Vm}^{-1}$

$\therefore$ The required expression for the oscillating electric field is

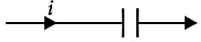
$$E_Z = E_0 \sin\left(\frac{2\pi x}{\lambda} + \frac{2\pi t}{T}\right)$$

$= 2400 \sin (300\, \pi x + 2 \times 10^{11}\, t)$ V/m.

22. Maxwell's generalization of Ampere's circuital Law,

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

In the process of charging the capacitor there is change in electric flux between the capacitor plates.



$$\frac{d\phi_E}{dt} = \frac{d}{dt}(EA)$$

$E \rightarrow$ Electric field between the plates $= \frac{q}{A\varepsilon_0}$

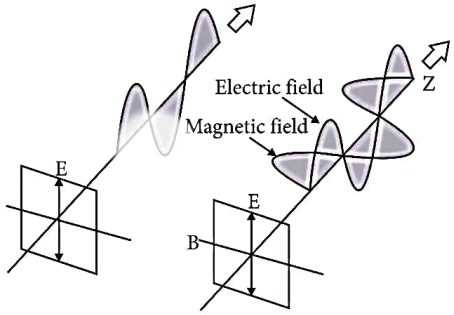
$A \rightarrow$ Area of the plate

$$\text{So,} \quad \frac{d\phi_E}{dt} = \frac{d}{dt}\left(\frac{q}{A\varepsilon_0} \times A \right) = \frac{1}{\varepsilon_0}\frac{dq}{dt} = \frac{i_d}{\varepsilon_0}$$

$$\therefore \quad i_d = i = \varepsilon_0 \frac{d\phi_E}{dt}$$

23. *Refer to answer 17 (a).*

A plane electromagnetic wave is said to be linearly polarized. The transverse electric field wave accompanied by a magnetic field wave is illustrated.



24. (a) Microwaves are suitable for radar system used in aircraft navigation.

(b) X-rays are produced by bombarding a metal target by high speed electrons.

(ii) *Refer to answer 6.*

25. (a) Microwaves are suitable for the radar system used in aircraft navigation. Range of frequency of microwaves is 10^8 Hz to 10^{11} Hz.

(b) If the Earth did not have atmosphere, then there would be absence of green house effect of the atmosphere. Due to this reason, the temperature of the earth would be lower than what it is now.

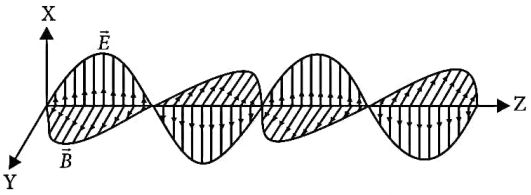
(c) An *e.m.* wave carries momentum with itself and given by

$$P = \frac{\text{Energy of wave } (U)}{\text{Speed of the wave } (c)}$$

When it is incident upon a surface it exerts pressure on it.

26. *Refer to answer 17 (a).*

27. (a) (i)



Propagation of wave is along *Z*-axis.

(ii) Speed of *e.m.* wave can be given as the ratio of magnitude of electric field (E_0) to the magnitude of magnetic field (B_0), *i.e.*, $c = \frac{E_0}{B_0}$

(b) *Refer to answer 17(b).*

28. (a) *Refer to answer 17(a).*

(b) *Refer to answer 27(a) (i).*

For an *e.m.* wave propagating in *Z*-direction, electric field is directed along *X*-axis and magnetic field is directed along *Y*-axis.

$\hat{k} = \hat{i} \times \hat{j}$

29. *Refer to answer 17(a).*

30. (a) Keen observer / helpful / concerned / responsible /respectful towards elders.

(b) During the intake of different elements and compounds, the biological organisms absorbs them differently. Also, the exact distribution of the elements and their function in the various parts of organisms cannot be known clearly. For this, a radioisotope is made to enter the organism along with the elements and compounds, whose absorption, function and distribution to the brain has to be studied. The radioisotope acts as a tag of label for the element or compound under study. By detecting the radiation emitted by the isotope from the brain, the details regarding the absorption and function of the compounds by the organisms are found out. In this way, radioisotopes help a doctor to diagnose brain tumour.

31. (a) Caring, sharing and concern.

(b) X-rays, gamma rays and charged particle are type of radiation used for tumer. Radiation given to the brain to shrink tumors formed cancer cells.

(c) γ-rays are emitted by nucleus for coming down to a lower energy level.

32. X-rays.

33. Microwaves < Infra-red rays < Ultraviolet rays < γ-rays.

34. (i) Infra-red rays (ii) Microwaves.

35. The electric and magnetic field vectors $\vec{E}$ and $\vec{B}$ are perpendicular to each other and also perpendicular to the direction of propagation of the electromagnetic wave. If a plane electromagnetic wave is propagating along the *z*-direction, then the electric field is along *x*-axis, and magnetic field is along *y*-axis.

36. Radio waves are the electromagnetic waves of frequency ranging from 500 KHz to about 1000 MHz. These waves are produced by oscillating electric circuits having inductor and capacitor.

37. Uses of microwaves :

(i) In long distance communication

(ii) In radar

38. Gamma rays (frequency range > 3×10^{21} Hz) has largest penetrating power.

39. The wavelength range of 10^{-10}, lies in X-rays. X-rays are used as a diagnostic tool in medicine and as a treatment for certain forms of cancer.

40. Short radio waves $\lambda > 0.1$ m or $\upsilon < 3 \times 10^9$ Hz are used in satellite communication.

41. The ascending order of the frequencies of the radiation are :

Radio waves < Microwaves < UV rays < X-rays.

42. Microwave (Range 0.1 m to 10^{-3} m)

Application : Microwaves are used in radar system for aircraft navigation.

43. (a) Descending order of wavelength for given electromagnetic wave are:

Microwaves ($10^{-3} - 10^{-1}$)

Infra-red rays ($7.5 \times 10^{-7} - 10^{-3}$)

Ultra-violet radiation ($10^{-9} - 4 \times 10^{-7}$)

Gamma rays ($< 10^{-12}$)

(b) Microwaves :

Frequency range → 3×10^8 Hz -3×10^{11} Hz. These are suitable for the radar system, used in aircraft navigation.

Gamma rays :

Frequency range → > 3×10^{21} Hz.

These wave are used for the treatment of cancer cells.

44. *Refer to answer 15 (b).*

Infra-red radiations play an important role in maintaining the earth's warmth or average

temperature through the greenhouse effect.

45. (i) Microwave : are used in radar system for aircraft navigation. The frequency range is 3×10^8 to 3×10^{11}.
(ii) X-rays are used for studying crystals structure of solids. Their frequency range is 3×10^{16} Hz to 3×10^{21} Hz.

46. Given electromagnetic radiations in ascending order of their frequencies are Radio wave, Microwave, X-rays, Gamma rays.

47. (i) X-rays are produced in X-ray tube or inner shell electron.
(ii) X-rays are dected in Geiger tube or through photographic film.

48. (i) Microwaves are produced by special vacuum tubes klystron valve.
(ii) Microwaves are detected through point contact diodes.

49. (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 *e.m.* 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.

50. (a) Microwaves are suitable for radar systems used in aircraft navigation.
These waves are produced by special vacuum tubes, namely klystrons, magnetrons and Gunn diodes.
(b) Infra-red waves are used to treat muscular pain. These waves are produced by hot bodies and molecules.
(c) X-rays are used as a diagnostic tool in medicine. These are produced when high energy electrons are stopped suddenly on a metal of high atomic number.

51. 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.
Microwaves are short wavelength radio waves, with frequency of order of GHz. Due to short wavelength, they have high penetrating power with respect to atmsophere and less diffraction in theatmospheric layers. So these waves are suitable for the radar systems used in aircraft navigation.

52. (i) Microwaves : These are used in Radar system for aircraft navigation.
(ii) Ultraviolet rays : These are used to destroy the bacteria and for sterilizing surgical instruments.
(iii) Infra-red rays : These are used to treat mauscular pain.
(iv) Gamma rays : These are used for the treatment of cancer.

53. Four characteristics of electromagnetic waves are :
1. Electromagnetic waves do not require any medium for their propagation.
2. These waves travel in free space with speed 3×10^8 m/s. It is given by the relation

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

3. The energy in electromagnetic waves is divided equally between electric field and magnetic field.
4. E.M. waves are produced by accelerated charged particles.
(i) Uses of radio-waves.
1. Radio -waves are used in radio and television communication.
2. Cellular phones use radio-waves in the ultra high frequency (UHF) band.
(ii) Uses of micro-waves :
1. Microwaves are used in Radar system for aircraft navigation.
2. Microwaves are used in speed guns to detect the speed of tennis ball, cricket ball, automobile while in motion.

54. (i) Infra-red waves
Use : For producing dehydrated fruits.
(ii) Ultraviolet light
Use : These are used to destroy the bacteria and for sterilizing surgical instruments.
(iii) Microwaves
Use : Radar system in aircraft navigation uses microwaves.