Electromagnetic Waves

Unit 5

BASIC CONCEPTS AND FORMULAE

1. **Need for Displacement Current**

Ampere's circuital law for conduction current during charging of a capacitor was found inconsistent. therefore Maxwell modified Ampere's circuital law by introducing displacement current. It is given by $I_d = \varepsilon_0 \frac{d\phi_E}{dt}$

Modified Ampere's circuital law is:

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

where ϕ_E = electric flux.

2. **Electromagnetic Waves**

The waves propagating in space through electric and magnetic fields varying in space and time simultaneously are called electromagnetic waves.

3. **Origin**

The electromagnetic waves are produced by an accelerated or decelerated charge or LC circuit. The frequency of *em* waves is

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

4. **Characteristics of Electromagnetic Waves**

(*i*) The electromagnetic waves travel in free-space with the speed of light ($c = 3 \times 10^8$ m/s) irrespective of their wavelength.

(*ii*) Electromagnetic waves are neutral, so they are not deflected by electric and magnetic fields.

(*iii*) The electromagnetic waves show properties of reflection, refraction, interference, diffraction and polarisation.

(*iv*) In electromagnetic wave the electric and magnetic fields are always in the same phase.

(*v*) The ratio of magnitudes of electric and magnetic field vectors in free space is constant equal to *c*.

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

(*vi*) The speed of electromagnetic waves in a material medium is given by

$$v = \frac{1}{\sqrt{\mu\,\varepsilon}} = \frac{c}{\sqrt{\mu_r \varepsilon_r}} = \frac{c}{n}, \quad \text{where } n \text{ is the refractive index.}$$

(*vii*) In an electromagnetic wave the energy is propagated by means of electric and magnetic field vectors in the direction of propagation of wave.

(*viii*) In electromagnetic wave the average values of electric energy density and magnetic energy density are equal

$$\left(\frac{1}{2}\varepsilon_0 E^2\right)_{av} = \left(\frac{B^2}{2\mu_0}\right)_{av}$$

(*ix*) The electric vector of electromagnetic wave is responsible for optical effects and is also called the light vector.

5. Transverse Nature of Electromagnetic Waves

The electromagnetic waves are **transverse in nature.** In electromagnetic waves the electric and magnetic fields are mutually perpendicular and also perpendicular to the direction of wave' propagation, such that $\vec{E}$, $\vec{B}$ and $\vec{K}$ form a right handed set ($\vec{K}$ is propagation vector along the direction of propagation).

6. Electromagnetic Spectrum

The electromagnetic waves have a continuous wavelength starting from short gamma rays to long radiowaves. The orderly distribution of wavelength of em waves is called the electromagnetic spectrum. The complete spectrum is given in the following table:

S. No.	Name	Wavelength Range (m)	Frequency Range (Hz)
i.	Gamma rays	$10^{-13} - 10^{-10}$	$3 \times 10^{21} - 3 \times 10^{18}$
ii.	*X*-rays	$10^{-10} - 10^{-8}$	$3 \times 10^{18} - 3 \times 10^{16}$
iii.	Ultraviolet rays	$10^{-8} - 4 \times 10^{-7}$	$3 \times 10^{16} - 7.5 \times 10^{14}$
iv.	Visible light	$4 \times 10^{-7} - 7.5 \times 10^{-7}$	$7.5 \times 10^{14} - 4 \times 10^{14}$
v.	Infra red light	$7.5 \times 10^{-7} - 10^{-3}$	$4 \times 10^{14} - 3 \times 10^{11}$
vi.	Microwaves	$10^{-3} - 10^{-1}$	$3 \times 10^{11} - 10^{10}$
vii.	Radio waves	$10^{-1} - 10^{4}$	$10^{10} - 3 \times 10^{4}$

7. Wavelength Range of Visible Spectrum

Visible light has a continuous wavelength starting from 400 nm to 750 nm; for convenience it is divided into 7 colours.

V	Violet	400 nm — 420 nm
I	Indigo	420 nm — 450 nm
B	Blue	450 nm — 500 nm
G	Green	500 nm — 570 nm
Y	Yellow	570 nm — 600 nm
O	Orange	600 nm — 650 nm
R	Red	650 nm — 750 nm

8. Uses of Electromagnetic Spectrum

(*i*) **γ-rays** are highly penetrating, they can penetrate thick iron blocks. Due to high energy, they are used to initiate some nuclear reactions. γ-rays are produced in nuclear reactions. In medicine, they are used to destroy cancer cells.

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

(*iii*) **Ultraviolet rays** provide vitamin *D*. These are harmful for skin and eyes. They are used to sterilise drinking water and surgical instruments. They are used to detect invisible writing, forged documents, finger prints in forensic lab and to preserve food stuffs.

(iv) **Infrared rays** are produced by hot bodies and molecules. These waves are used for long distance photography and for therapeutic purposes.

(v) **Radiowaves** are used for broadcasting programmes to distant places. According to frequency range, they are divided into following groups

(1) Medium frequency band or medium waves 0·3 to 3 MHz

(2) Short waves or short frequency band 3 MHz — 30 MHz

(3) Very high frequency (VHF) band 30 MHz to 300 MHz

(4) Ultrahigh frequency (UHF) band 300 MHz to 3000 MHz

(vi) **Microwaves** are produced by special vacuum tubes, namely; klystrons, magnetrons and gunn diodes. Their frequency range is 3 GHz to 300 GHz.

They are used in RADAR systems for air craft navigation and microwave used in homes.

IMPORTANT QUESTIONS

[A] Remembering & Understanding-based Questions

Very Short Answer Questions (1 mark)

Q. 1. Why did Maxwell introduce displacement current in Ampere's circuital law?

Ans. Ampere's circuital law was found inconsistent when applied to the circuit for charging a capacitor. Therefore Maxwell added displacement current to usual conduction current.

The displacement current is

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

where ϕ_E is electric flux.

Q. 2. What is the origin of displacement current?

Ans. Displacement current does not arise due to motion of charge carriers but it arises due to time variation of electric flux.

Q. 3. A capacitor has been charged by a dc source. What are the magnitudes of conduction and displacement currents, when it is fully charged? *[CBSE Delhi 2013]*

Ans. During charging of a capacitor by a dc source,

$$I_c = I_d = \frac{e_0 dj_E}{dt}$$

When capacitor is fully charged than (φ_E) = Max

So $I_c = I_d = 0$

Q. 4. The wavelength of electromagnetic radiation is doubled. What will happen to the energy of the photon ?

Ans. Energy of a photon $E = h\nu = \frac{hc}{\lambda}$, *i.e.*, $E \propto \frac{1}{\lambda}$

When wavelength λ is doubled, the energy of photon will be reduced to half.

Q. 5. What is the unit of ratio $\frac{E}{H}$?

Ans. The unit of $\frac{E}{H}$ is volt/ampere or ohm.

Q. 6. What are the directions of electric and magnetic field vectors relative to each other and relative to the direction of propagation of electromagnetic waves? *[CBSE (AI) 2012]*

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

Q. 7. Name the physical quantity which remains same for microwaves of wavelength 1 mm and UV radiations of 1600 Å in vacuum. **[CBSE Delhi 2012]**

Ans. Velocity ($c = 3\times10^8$ m/s)

This is because both are electromagnetic waves.

Q. 8. The speed of an electromagnetic wave in a material medium is given by $v = \frac{1}{\sqrt{\mu\varepsilon}}$, μ being the permeability of the medium and ε its permittivity. How does its frequency change? **[*CBSE (AI) 2012*]**

Ans. The frequency of electromagnetic waves does not change while travelling through a medium.

Q. 9. Name the characteristics of electromagnetic waves that

(*i*) increases **(*ii*) remains constant.**

in the electromagnetic spectrum as one moves from radiowave region towards ultraviolet region.

Ans. (*i*) Frequency increases. (*ii*) Speed in vacuum remains constant.

Q. 10. Which of the following can act as a source of electromagnetic waves

(*i*) A charge moving with a constant velocity

(*ii*) A charge moving in a circular orbit

(*iii*) A charge at rest

Give reason.

Ans. Only an accelerated charge can radiate electromagnetic waves. As charge moving in a circular orbit is accelerated, so it can radiate electromagnetic waves.

Q. 11. What physical quantity is the same for X-rays of wavelength 10^{-10} m, red light of wavelength 6800 Å and radiowaves of wavelength 500 m? **[*NCERT*]**

Ans. *X*-rays, red light and radiowaves are all electromagnetic waves. The speed of propagation in vacuum is the same for all these waves. This speed is equal to $c = 3\times10^8$ m/s.

Q. 12. A charged particle oscillates about its mean (equilibrium) position with a frequency of 10^9 Hz. What is the frequency of the electromagnetic waves produced by the oscillator? **[*NCERT*]**

Ans. According to Maxwell's theory, an oscillating charged particle with a frequency ν radiates electromagnetic waves of frequency ν.

So the frequency of electromagnetic waves produced by the oscillator is $\nu = 10^9$ Hz.

Q. 13. Long distance radio broadcasts use short wave bands, why? **[*NCERT*]**

Ans. Radio broadcasts use the reflection of transmitted waves through different ionospheric layers. These layers reflect short wavelength bands.

Q. 14. It is necessary to use satellites for long distance T.V. transmission. Why? [*NCERT; CBSE Delhi 2014*]

Ans. T.V. signals are not properly reflected by ionosphere. Therefore, signals are made to be reflected to earth by using artificial satellites.

Q. 15. Optical and radiotelescopes are built on the ground but X-ray astronomy is possible only from a satellite orbiting the earth, why? **[*NCERT; CBSE (AI) 2009*]**

Ans. The visible radiations and radiowaves can penetrate the earth's atmosphere but X-rays are absorbed by the atmosphere.

Q. 16. Some scientists have predicted that a global nuclear war on the earth would be followed by a severe nuclear winter' with a devastating effect on life on earth. What might be the basis of this prediction? **[*NCERT*]**

Ans. Scientists think that in case of a global nuclear war, the clouds produced would cover almost the whole of the sky. So infrared radiation emitted by the sun would not reach earth, this would cause a nuclear winter on earth.

Q. 17. Which of the following radiations are (*i*) heat radiation and (*ii*) used for long distance transmission? Infrared rays, gamma rays, ultraviolet rays, microwaves.

Ans. Infrared rays are heat radiation, Microwaves are used for long distance transmission.

Q. 18. Which part of electromagnetic spectrum does the wavelength 10^{-10} m correspond to?

Ans. X-rays.

Q. 19. Which of the following has the least wavelength ? Gamma rays, blue light, infrared radiation and ultraviolet radiation.

Ans. Gamma rays have the least wavelength.

Q. 20. Which of the following has the minimum wavelength and which has the maximum wavelength ? Blue light, infrared rays, gamma rays, green light.

Ans. Out of the given wavelengths gamma rays have the minimum wavelength and infrared rays have the maximum wavelength.

Q. 21. A plane electromagnetic wave travels in vacuum along z-direction. What can you say about the direction of electric and magnetic field vectors ? **[*CBSE Delhi 2011*]**

Ans. Electric field vector along X-axis

Magnetic field vector along Y-axis.

Q. 22. Which part of the electromagnetic spectrum has the largest penetrating power? **[*CBSE Delhi 2010*]**

Ans. γ-rays.

Q. 23. To which part of the electromagnetic spectrum does a wave of frequency 5×10^{19} Hz belong? **[*CBSE (AI) 2014*]**

Ans. X-rays or γ-rays.

Q. 24. How are infrared waves produced?

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

Q. 25. To which part of the electromagnetic spectrum does a wave of frequency 3×10^{13} Hz belong? **[*CBSE (AI) 2014*]**

Ans. Infrared radiation

Q. 26. Identify the part of the electromagnetic spectrum to which the following wavelengths belong:
(*i*) 10^{-1} m **(*ii*) 10^{-12} m** **[*CBSE (AI) 2008*]**

Ans. (*i*) 10^{-1} m = 10 cm belongs to **short radiowaves.**

(*ii*) 10^{-12} m = 0.01 Å belongs to **gamma rays.**

Q. 27. Name the part of the electromagnetic spectrum of wavelength 10^{-2} m and mention its one application. **[*CBSE Delhi 2008*]**

Ans. Microwave.

Application : Used in RADAR system for aircraft navigation.

Q. 28. Identify the part of the electromagnetic spectrum to which the following wavelengths belong:
(*i*) 1 mm **(*ii*) 10^{-11} m** **[*CBSE (AI) 2008*]**

Ans. (*i*) wavelength 1 **mm** belongs to the **microwaves.**

(*ii*) wavelength 10^{-11} **m** = 0.1 Å belongs to **gamma rays.**

Q. 29. Which part of the electromagnetic spectrum is used in operating a RADAR? **[*CBSE Delhi 2010*]**

Ans. Microwaves are used in operating a RADAR.

Q. 30. Why are microwaves used in RADAR ?

Ans. Microwaves are electromagnetic waves having wave length of the order of a few millimetres. They are used in RADAR because they can be transmitted as a beam in a given direction without any bending.

Q. 31. Which part of the electromagnetic spectrum is absorbed from sunlight by ozone layer? **[*CBSE Delhi 2010*]**

Ans. Ultraviolet light is absorbed by the ozone layer.

Q. 32. 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. **[*CBSE (AI) 2013*]**

Ans. Ultraviolet radiations or Radiations above violet (in VIBGYOR)

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

Hint: *Frequency of visible light is of the order of 10^{14} Hz.*

Q. 33. Name the electromagnetic radiations used for studying the crystal structure of solids. **[CBSE (AI) 2007]**

Ans. X-rays.

Q. 34. Name the electromagnetic radiations used for viewing objects through haze and fog.

Ans. Infrared rays are used for viewing objects through haze and fog.

Q. 35. Name the part of electromagnetic spectrum which is used for taking photographs of earth under foggy conditions from great heights.

Ans. Infrared radiation.

Q. 36. Name the electromagnetic waves that have frequencies greater than those of ultraviolet light but less than those of gamma rays.

Ans. X-ray.

Q. 37. Name the electromagnetic waves, which (*i*) maintain the Earth's warmth and (*ii*) are used in aircraft navigation. **[CBSE (F) 2012]**

Ans. (*i*) Infrared rays (*ii*) Microwaves.

Q. 38. Why are infra-red radiations referred to as heat waves? Name the radiations which are next to these radiations in the electromagnetic spectrum having (i) shorter wavelength (ii) longer wavelength. **[CBSE (F) 2013]**

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

Em wave having short wavelength than infrared waves are visible, UV, X-rays and γ-rays.

(*i*) Em wave having short wavelength than infrared waves are visible, UV, X-rays and γ-rays.

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

Q. 39. What is the ratio of speed of infrared rays and ultraviolet rays in vacuum?

Ans. All electromagnetic waves travel in vacuum with the same speed.

$$\text{Ratio} = \frac{c_{infrared}}{c_{ultra\,violet}} = 1$$

Q. 40. What is the ratio of speed of γ-rays and radiowaves in vacuum ?

Ans.
$$\frac{c_{\gamma-rays}}{c_{radiowaves}} = 1$$

Q. 41. Name the part of the electromagnetic spectrum of wavelength 10^{-2} m and mention its one application. **[CBSE Delhi 2008]**

Ans. Wavelength 10^{-2} m belongs to microwaves. It is used in RADAR.

Q. 42. Name the part of electromagnetic spectrum of wavelength 10^2 m and mention its one application. **[CBSE Delhi 2005, 2008]**

Ans. Wavelength 10^2 m belongs to radio-waves. This is used to broadcast radio programmes to long distances.

Q. 43. How are X-rays produced? **[CBSE (AI) 2011]**

Ans. X-rays are produced when high energetic electron beam is made incident on a metallic target of high melting point and high atomic weight.

Q. 44. The following table gives the wavelength range of some constituents of the electromagnetic spectrum.

S. No.	Wavelength Range
1.	1 mm to 700 nm
2.	400 nm to 1 nm
3.	1 nm to 10^{-3} nm
4.	$< 10^{-3}$ nm

Select the wavelength range and name the electromagnetic waves that are

(*i*) widely used in the remote switches of household electronic devices.

(*ii*) produced in nuclear reactions. **[CBSE Delhi 2008C]**

Ans. (*i*) Infrared waves (wavelengh range 1 mm to 700 nm).

(*ii*) Gamma rays (wavelength range $<10^{-3}$ nm).

Q. 45. **Special devices, like the klystron valve or the magnetron valve, are used for production of electromagnetic waves. Name the waves and also write one of their applications. [*CBSE Delhi 2008C*]**

Ans. **Name:** Microwaves.

Use: For cooking in microwaves ovens.

Q. 46. **The frequency of oscillation of the electric field vector of a certain electromagnetic wave is 5×10^{14} Hz. What is the frequency of oscillation of the corresponding magnetic field vector and to which part of the electromagnetic spectrum does it belong? [*CBSE (AI) 2008C*]**

Ans. Frequency of oscillation of magnetic field vector is same as that of electric field vector *i.e.,*

$$\nu = 5 \times 10^{14} \text{ Hz}$$

It lies in visible region.

Q. 47. **From the following, identify the electromagnetic waves having the (*i*) Maximum (*ii*) Minimum frequency.**

(*a*) Radio waves (*b*) Gamma-rays

(*c*) Visible light (*d*) Microwaves

(*e*) Ultraviolet rays, and (*f*) Infrared rays.

Ans. (*i*) The waves of maximum frequency are gamma rays.

(*ii*) The waves of minimum frequency are radio waves.

Q. 48. **Write the following radiations in ascending order in respect of their frequencies: *X*-rays, microwaves, ultraviolet rays and radiowaves and gamma rays. [*CBSE Delhi 2010*]**

Ans. In ascending order of frequencies : radiowaves, microwaves, ultraviolet rays, *X*-rays and gamma rays.

Q. 49. **Give a reason to show that microwaves are better carriers of signals for long range transmission than radio waves.**

Ans. Microwaves are short wavelength waves, so they go straight in a specified direction without any bending.

Q. 50. **Which out of the following are electromagnetic waves : *X*-rays, sound waves and radiowaves?**

Ans. *X*-rays and radiowaves are electromagnetic waves.

Q. 51. **Is the ratio of frequencies of ultraviolet rays and infrared rays in glass more than, less than or equal to 1 ?**

Ans. Ultraviolet rays have more frequency than infrared rays hence ratio is :

$$\frac{\nu_{ultraviolet}}{\nu_{infrared}} > 1$$

Q. 52. **Which of the following has the shortest wavelength?**

Microwaves, Ultraviolet rays, X-rays [*CBSE (AI) 2010*]

Ans. X-rays has shortest wavelength.

Short Answer Questions (2, 3 marks)

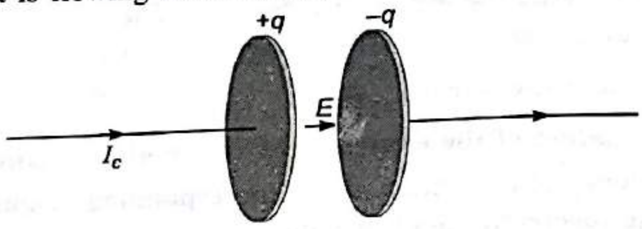
Q. 1. **A capacitor of capacitance '*C*' is being charged by connecting it across a dc source along with an ammeter. Will the ammeter show a momentary deflection during the process of charging? If so, how would you explain this momentary deflection and the resulting continuity of current in the circuit? Write the expression for the current inside the capacitor. [*CBSE (AI) 2012*]**

Ans. Yes, because of the production of displacement current between the plates of capacitor on account of changing electric field.

Current inside the capacitor is given by: $I_D = \varepsilon_0 \dfrac{d\phi_E}{dt}$

Q. 2. 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. **[CBSE (AI) 2013]**

Ans. In Fig. conduction current is flowing in the wires, causes charge on the plates



So $I_c = \dfrac{dq}{dt}$ ...(*i*)

According to Maxwell, displacement current between plates,

$I_d = \varepsilon_0 \dfrac{d\phi_E}{dt}$, where ϕ_E = Electric flux ...(*ii*)

Using Gauss's theorem, if one of the plate is inside the tiffin type Gaussian surface, then

$$\phi_E = \frac{q}{\varepsilon_0}$$

So $I_d = \varepsilon_0 \dfrac{d}{dt}\left(\dfrac{q}{\varepsilon_0}\right)$

$I_d = \dfrac{dq}{dt}$ ...(*iii*)

From equation (*i*) and (*iii*),
Both conduction current and displacement currents are equal.

Q. 3. Write the generalised expression for the Ampere's circuital law in terms of the conduction current and the displacement current. Mention the situation when there is:

(*i*) only conduction current and no displacement current.

(*ii*) only displacement current and no conduction current. ***[CBSE (F) 2013]***

Ans. Generalised Ampere's circuital Law—

$$\oint \vec{B}\cdot\vec{dl} = \mu_0 I_C + \mu_0\varepsilon_0 \frac{d\phi_E}{dt}$$

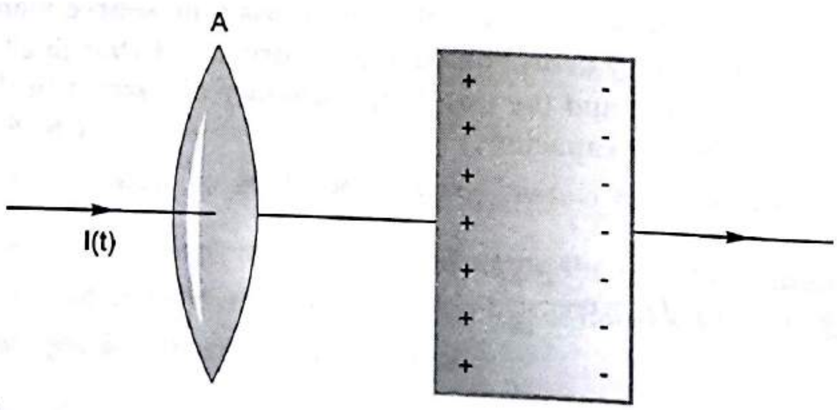
Line integral of magnetic field over closed loop is equal to μ_0 times sum of conduction current and displacement current.

(*i*) In case of steady electric field in a conducting wire, electric field does not change with time, conduction current exists in the wire but displacement current may be zero. So, $\oint \vec{B}\cdot\vec{dl} = \mu_0 I_C$.

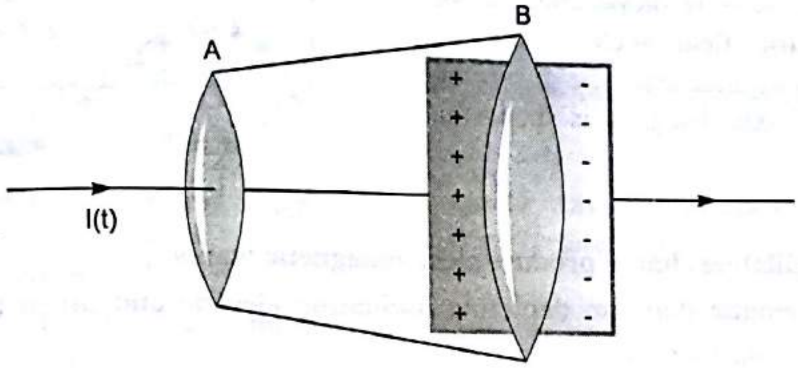
(*ii*) In large region of space, where there is no conduction current, but there is only a displacement current due to time varying electric field (or flux). So, $\oint \vec{B}\cdot\vec{dl} = \mu_0\varepsilon_0 \dfrac{d\phi_E}{dt}$.

Q. 4. Considering the case of a parallel plate capacitor being charged, show how one is required to generalise Ampere's circuital law to include the term due to displacement current. ***[CBSE (AI) 2014]***

Ans.



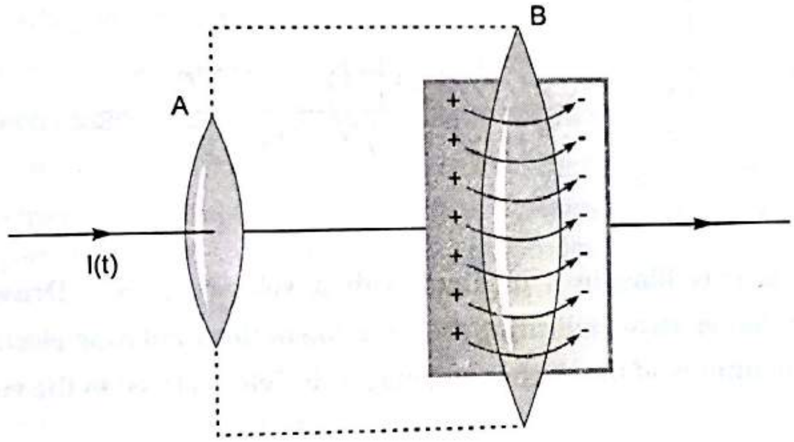
During charging C capacitor, a time varying current $I(t)$ flows through the conducting wire, so on applying Ampere's circuital law (for loop A) $\oint \vec{B}.\vec{dl} = \mu_o I(t)$ ... (*i*)



Now we consider a pot like surface enclosing the positively charged plate and nowhere touches the conducting wire,

$$\oint \vec{B}.\vec{dl} = 0 \qquad \text{... }(ii)$$

From equation (*i*) and (*ii*), we have a contradiction



If surfaces A and B forms a tiffin box, and electric field $\vec{E}$ is passing through the surface (B); constitute an electric flux

$$\phi = |E||A| = \frac{\sigma}{\varepsilon_0}|A| = \frac{Q}{A\varepsilon_0}|A| = \frac{Q}{\varepsilon_0} \qquad \text{... }(iii)$$

If the charge on the plate in the tiffin box is changing with time, there must be a current between the plates.

From equation (*iii*)

$$I = \frac{dQ}{dt} = \frac{d}{dt}(\varepsilon_0 \phi) = \varepsilon_0 \frac{d\phi}{dt}$$

This is the missing term in Ampere's circuital law.

The inconsistency may disappear if displacement current is included between the plates.

So generalised Ampere's circuital law can be given as

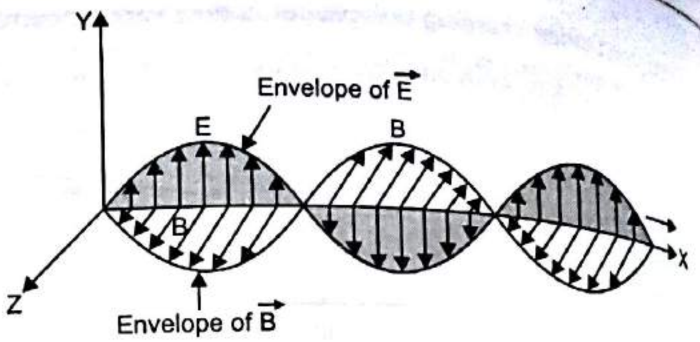
$$\oint \vec{B}.\vec{dt} = \mu_0 I_{(t)} + \mu_0 Id = \mu_0 I_{(t)} + \mu_0 \varepsilon_0 \frac{d\phi}{dt}$$

Q. 5. What is meant by the transverse nature of electromagnetic waves ? Draw a diagram showing the propagation of an electromagnetic wave along *X*-direction, indicating clearly the directions of oscillating electric and magnetic fields associated with it. **[*CBSE (AI) 2008*]**

Ans. Transverse Nature of Electromagnetic Waves :

In an electromagnetic wave, the electric and magnetic field vectors oscillate, perpendicular to the direction of propagation of wave. This is called transverse nature of electromagnetic wave.

In an electromagnetic wave, the three vectors $\vec{E}, \vec{B}$ and $\vec{K}$ form a right handed system. Accordingly if a wave is propagating along X-axis, the electric field vector oscillates along Y-axis and magnetic field vector oscillates along Z-axis. Diagram is shown in figure.

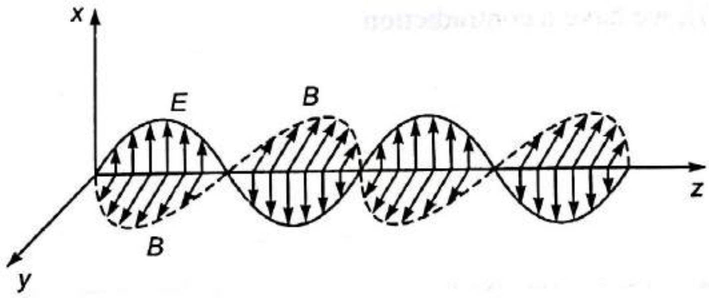


Q. 6. **(*a*) How does oscillating charge produce electromagnetic waves?**

(*b*) Sketch a schematic diagram depicting oscillating electric and magnetic fields of an em wave propagating along + z-direction. ***[CBSE (F) 2014]***

Ans. (*a*) An oscillating charge produces an oscillating electric field in space, which produces an oscillating magnetic field. The oscillating electric and magnetic fields regenerate each other, and this results in the production of em waves in space.

(*b*) Electric field is along x-axis and magnetic field is along y-axis.



Q. 7. **(a) An em wave is travelling in a medium with a velocity $\vec{v} = v\hat{i}$. Draw a sketch showing the propagation of the *em* wave, indicating the direction of the oscillating electric and magnetic fields.**

(b) How are the magnitudes of the electric and magnetic fields related to the velocity of the *em* wave? ***[CBSE Delhi 2013]***

Ans. The direction of propagation of electromagnetic wave is given by $\vec{E} \times \vec{B}$

For diagram refer to SAQ 1.

(*a*) $\hat{i} = \hat{j} \times \hat{k}$.

(*b*) The speed of electromagnetic wave $|c| = \frac{|E_0|}{|B_0|}$

Q. 8. **What do electromagnetic waves consist of ? Explain on what factors does its velocity in vacuum depend?**

Ans. Electromagnetic waves consist of mutually perpendicular electric and magnetic field vectors. Its velocity in vacuum is given by

$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$ is same for all electromagnetic waves.

In other words its velocity in vacuum does not depend on any factor.

Q. 9. **Give two characteristics of electromagnetic waves. Write the expression for velocity of electromagnetic waves in terms of permittivity and permeability of the medium.**

Ans. Characteristics of electromagnetic waves:

(*i*) Electromagnetic waves travel in free space with speed of light $c = 3 \times 10^8$ m/s.

(*ii*) Electromagnetic waves are transverse in nature.

Expression for velocity of *em* waves in vacuum, $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$

Q. 10. A plane electromagnetic wave travels in vacuum, along the Y-direction. Write down the (*i*) ratio of the magnitudes and (*ii*) the direction, of its electric and magnetic field vectors. [*CBSE Delhi 2004C*]

Ans. (*i*) $\frac{E}{B}$ = speed of light ($c = 3 \times 10^8$ m/s)

(*ii*) $\vec{K}$, $\vec{E}$, $\vec{B}$ form a right handed system. As wave propagation vector ($\vec{K}$) is along Y-axis; electric field ($\vec{E}$) must be along Z-axis and magnetic field $\vec{B}$ along X-axis.

Q. 11. When can a charge act as a source of electromagnetic wave ? How are the directions of electric and magnetic field vectors, in an electromagnetic wave related to each other and to the direction of propagation of the wave?

Which physical quantity, if any, has the same value for waves belonging to the different parts of the electromagnetic spectrum?

Ans. **Source of Electromagnetic Waves :** The source of electromagnetic waves is an accelerated (or decelerated) charge or an oscillating LC circuit. In an electromagnetic wave, the electric field vector $\vec{E}$ and magnetic field vector $\vec{B}$ are mutually perpendicular and also perpendicular to direction of wave propagation such that wave propagation vector $\vec{K}$, electric field vector $\vec{E}$ and magnetic field vector $\vec{B}$, form a right handed orthogonal system.

The speed of waves in vacuum is the same for different parts of electromagnetic spectrum.

Q. 12. (*a*) **How are electromagnetic waves produced by oscillating charges?**

(*b*) **State clearly how a microwave oven works to heat up a food item containing water molecules.**

(*c*) **Why are microwaves found useful for the radar systems in aircraft navigation? [*CBSE (F) 2013*]**

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

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

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

Q. 13. Identify the following electromagnetic radiations as per the wavelengths given below.

(*a*) 10^{-3} nm (*b*) 10^{-3} m (*c*) 1 nm

Write one application of each. [*CBSE (AI) 2008*]

Ans. (*a*) 10^{-3} nm $\rightarrow$ gamma radiation.

Application: Radio therapy or to initiate nuclear reactions.

(*b*) 10^{-3} m $\rightarrow$ microwaves

Application: In RADAR for aircraft navigation.

(*c*) 1 nm $\rightarrow$ X-ray.

Application: In medical science for detection of fractures, stones in kidney, gallbladder etc.

Q. 14. Identify the following electromagnetic radiations as per the frequencies given below:

(*a*) 10^{20} Hz (*b*) 10^9 Hz (*c*) 10^{11} Hz

Write one application of each. [*CBSE (AI) 2008*]

Ans. (*a*) 10^{20} Hz $\rightarrow$ γ-radiation.

Application: For treatment of cancer.

(*b*) 10^9 Hz $\rightarrow$ Radiowaves

Application: For broadcasting radio-programmes to long distances.

(*c*) 10^{11} Hz $\rightarrow$ Microwaves

Application: For cooking in microwave oven.

Q. 15. Name the part of the electromagnetic spectrum whose wavelength lies in the range 10^{-10} m. Give its one use. **[CBSE (AI) 2010]**

Ans. The electromagnetic waves having wavelength 10^{-10} m are X-rays.

X-rays are used to study crystal structure.

Q. 16. Experimental observations have shown that *X*-rays

(*i*) travel in vacuum with a speed of 3×10^8 ms^{-1}.

(*ii*) exhibit the phenomenon of diffraction and can be polarised.

What conclusion can be drawn about the nature of *X*-rays from each of these observations?

Ans. (*i*) *X*-rays are electromagnetic waves.

(*ii*) *X*-rays are transverse in nature.

Q. 17. Which constituent radiation of the electromagnetic spectrum is used

(*i*) in RADAR,

(*ii*) to photograph internal parts of a human body, and

(*iii*) for taking photographs of the sky during night and foggy conditions?

Give one reason for your answer in each case.

Ans. (*i*) **Microwaves** are used in RADAR because they go straight and are not absorbed by the atmosphere.

(*ii*) **X-rays** are used to photograph the internal parts of human body because they can penetrate light elements (flesh).

(*iii*) **Infrared radiations** are used for taking photographs of sky during light and foggy conditions because they penetrate fog and are not absorbed by the atmosphere.

Q. 18. Write the order of frequency range and one use of each of the following electromagnetic radiations:

(*i*) Microwaves **(*ii*) Ultraviolet rays** **(*iii*) Gamma rays** **[CBSE (AI) 2006]**

Ans. (*i*) **Microwaves:** Frequency range $\rightarrow 3 \times 10^{11}$ Hz $- 1 \times 10^8$ Hz. These are suitable for the RADAR systems, used in aircraft navigation.

(*ii*) **Ultraviolet rays:** Frequency range $\rightarrow 1 \times 10^{16}$ Hz $-$ 8×10^{14} Hz. They are used to detect invisible writing, forged documents and finger prints.

(*iii*) **Gamma rays:** Frequency range $\rightarrow 5 \times 10^{20}$ Hz $- 3 \times 10^{19}$ Hz. They are used for the treatment of cancer cells.

Q. 19. Name the constituent radiation of electromagnetic spectrum which **[CBSE (F) 2006, 2010]**

(*a*) is used in satellite communication.

(*b*) is used for studying crystal structure.

(*c*) is similar to the radiations emitted during the decay of radioactive nuclei.

(*d*) has its wavelength range between 390 nm and 700 nm.

(*e*) is absorbed from sunlight by ozone layer.

(*f*) produces intense heating effect.

Ans. (*a*) **Short radiowaves** $\lambda < 10$ m or $\nu > 30$ MHz are used in satellite communication.

(*b*) **X-rays** are used for studying crystal structure.

(*c*) **γ-radiation** is similar to the radiation emitted during the decay of radioactive nuclei.

(*d*) **Visible radiation** has a wavelength range of 390 nm–700 nm.

(*e*) **Ultraviolet light** is absorbed from sunlight by ozone layer.

(*f*) **Infrared radiation** produces intense heating effect.

Q. 20. To which regions of the electromagnetic spectrum, the following wavelengths belong? 2,000 Å, 5,000 Å, 10,000 Å and 1·0 Å.

Ans. 2,000 Å — Ultraviolet radiation   5,000 Å — Visible light

10,000 Å — Infrared radiation   1.0 Å — X-rays

Q. 21. Write the following in descending order of wavelength:

Gamma rays, Hertzian waves, yellow light, blue light, infrared radiation, ultraviolet radiation, X-rays, γ–rays.

Ans. Hertzian waves, infrared radiation, yellow light, blue light, ultraviolet radiation, X-rays, γ –rays.

Q. 22. Answer the following questions:

(*a*) Name the *em*-waves which are produced during radioactive decay of a nucleus. Write their frequency range.

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

(*c*) Why are infrared waves often called as heat waves? Give their one application. [*CBSE Delhi 2014*]

Ans. (*a*) *em* waves : γ-rays

Range : 10^{19} Hz to 10^{23} Hz

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

(c) Infrared waves are called heat waves because water molecules present in the materials readily absorb the infra red rays get heated up.

Application: They are used in green houses to warm the plants.

Q. 23. Answer the following:

(*a*) Name the *em* 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 em wave exerts pressure on the surface on which it is incident. Justify. [*NCERT; CBSE Delhi 2014*]

Ans. (*a*) Microwaves

Frequency range : 10^{10} Hz to 10^{12} Hz

(*b*) Average surface temperature will be lower. This is because there will be no green house effect in absence of atmosphere.

(*c*) An electromagnetic wave exerts pressure on the surface on which it is incident because these waves carry both energy and momentum.

Q. 24. Answer the following:

(*a*) Name the em waves which are used for the treatment of certain forms of cancer. Write their frequency range.

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

(*c*) Why is the amount of the momentum transferred by the em waves incident on the surface so small? [*CBSE Delhi 2014*]

Ans. (*a*) X rays or γ rays

Range: 10^{18} Hz to 10^{22} Hz.

(*b*) Ozone layer absorbs the ultraviolet radiations from the sun and prevents it from reaching the earth's surface.

(*c*) Momentum transferred, $p = \frac{u}{c}$

where u = energy transferred, and c = speed of light

Due to the large value of speed of light (c), the amount of momentum transferred by the em waves incident on the surface is small.

Short Answer Questions (2, 3 marks)

Q. 1. Find the wavelength of electromagnetic waves of frequency 5×10^{19} Hz in free space. Give its two applications.

Ans. Wavelength $\lambda=\frac{c}{\nu}=\frac{3\times10^8}{5\times10^{19}}=6\times10^{-12}$ m

These are gamma rays.
These are used for : (*i*) Nuclear reactions (*ii*) Radiotherapy.

Q. 2. Find the wavelength of electromagnetic waves of frequency 6×10^{12} Hz in free space. Give its two applications. ***[CBSE Delhi 2011]***

Ans. Wavelength $\lambda=\frac{c}{\nu}=\frac{3\times10^8}{6\times10^{12}}=5\times10^{-5}$ m.

This wavelength corresponds to infrared waves.

Applications of Infrared Rays

(*i*) They are used in green houses to warm the plants.

(*ii*) They are used in taking photographs during fogs.

Q. 3. Find the wavelength of electromagnetic waves of frequency 4×10^9 Hz in free space. Give its two applications.

Ans. Wavelength, $\lambda=\frac{c}{\nu}=\frac{3\times10^8}{4\times10^9}=\frac{3}{40}\text{ m}=\frac{300}{40}\text{ cm}=7.5$ cm.

This wavelength corresponds to microwave region (or short radiowaves).
These are used in (*i*) RADAR (*ii*) Microwave ovens.

Q. 4. 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? ***[CBSE Delhi 2012]***

Ans. When an ideal capacitor is charged by *dc* battery, charge flows (momentarily) till the capacitor gets fully charged.

When an *ac* source is connected then conduction current $i_c=\frac{dq}{dt}$ keep on flowing in the connecting wire. Due to changing current, charge deposited on the plates of the capacitor changes with time. This causes change in electric field between the plates of the capacitor which causes the electric flux to change and gives rise to a displacement current in the region between the plates of the capacitor.

As we know, displacement current

$$i_d=\varepsilon_0\frac{d\phi_E}{dt} \quad \text{and} \quad i_d=i_c \text{ at all instants.}$$

Q. 5. Explain briefly how electromagnetic waves are produced by an oscillating charge. How is the frequency of em waves produced related to that of the oscillating charge? ***[CBSE (F) 2012]***

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

The frequency of *em* wave = Frequency of oscillating charge

Q. 6. A plane electromagnetic wave travels in vacuum along Z-direction. What can you say about the directions of electric and magnetic field vectors ? If the frequency of the wave is 30 MHz, what is its wavelength ? ***[NCERT]***

Ans. In an electromagnetic wave's propagation vector $\vec{K}$, electric field vector $\vec{E}$ and magnetic field vector $\vec{B}$ form a right handed system. As the propagation vector is along Z-direction, electric field vector will be along X-direction and magnetic field vector will be along Y-direction.

Frequency $\nu = 30 \text{ MHz} = 30 \times 10^6 \text{ Hz}$

Speed of light, $c = 3 \times 10^8 \text{ ms}^{-1}$

$$\text{Wavelength, } \lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{30 \times 10^6} = 10 \text{ m}$$

Q. 7. A radio can tune into any station in the 7.5 MHz to 12 MHz band. What is the corresponding wavelength band ? [*NCERT*]

Ans. Speed of wave $c = 3 \times 10^8 \text{ ms}^{-1}$,

When frequency $\nu_1 = 7.5 \text{ MHz} = 7.5 \times 10^6 \text{ Hz}$, Wavelength $\lambda_1 = \frac{C}{\nu_1} = \frac{3 \times 10^8}{7.5 \times 10^6} = 40 \text{ m}$

When frequency $\nu_2 = 12 \text{ MHz}$, wavelength $\lambda_2 = \frac{C}{\nu_2} = \frac{3 \times 10^8}{12 \times 10^6} = 25 \text{ m}$

Wavelength band is from 25 m to 40 m.

Q. 8. The amplitude of the magnetic field 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*]

Ans. The relation between magnitudes of magnetic and electric field vectors in vacuum is

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

$$\Rightarrow \quad E_0 = B_0 c$$

Here, $B_0 = 510 \text{ nT} = 510 \times 10^{-9} \text{ T}, c = 3 \times 10^8 \text{ ms}^{-1}$,

$$E_0 = 510 \times 10^{-9} \times 3 \times 10^8 = 153 \text{ N/C}.$$

Q. 9. Suppose that the electric field amplitude of an electromagnetic wave is $E_0 = 120$ N/C and that its frequency $\nu = 50.0$ MHz. (*a*) Determine B_0, ω, k and λ (*b*) Find expressions for $\vec{E}$ and $\vec{B}$. [*NCERT*]

Ans. We have $\frac{E_0}{B_0} = c \Rightarrow B_0 = \frac{E_0}{c} = \frac{120}{3 \times 10^8} = 4 \times 10^{-7} \text{ T}$

$$\omega = 2\pi\nu = 2 \times 3.14 \times 50 \times 10^6$$

$$= 3 \cdot 14 \times 10^8 \text{ rad s}^{-1}$$

$$k = \frac{\omega}{c} = \frac{3.14 \times 10^8}{3 \times 10^8} = 1.05 \text{ rad m}^{-1}$$

$$\text{Wavelength, } \lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{50.0 \times 10^6} = 6.00 \text{ m}.$$

If wave is propagating along X-axis, electric field will be along Y-axis and magnetic field along Z-axis.

$\vec{E} = E_0 \sin(kx - \omega t)\ \hat{j}$, where x is in m and t in s.

$$\Rightarrow \quad \vec{E} = 120 \sin(1.05\, x - 3.14 \times 10^8\ t)\ \hat{j} \text{ N/C}$$

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

$$= (4 \times 10^{-7}) \sin(1.05\, x - 3.14 \times 10^8\ t)\ \hat{k} \text{ tesla.}$$

Q. 10. In a plane electromagnetic wave, the electric field oscillates sinusoidally at a frequency of 2.0×10^{10} Hz and amplitude 48 Vm^{-1}.

(a) What is the wavelength of a wave?

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

(c) Show that the average energy density of the electric field equals the average energy density of the B field. [$c = 3 \times 10^8$ ms^{-1}] **[NCERT]**

Ans. (a) Wavelength $\lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{2 \times 10^{10}} = 1.5 \times 10^{-2}$ m

(b) $B_0 = \frac{E_0}{c} = \frac{48}{3 \times 10^8} = 1.6 \times 10^{-7}$ tesla

(c) Energy density of electric field

$$u_e = \frac{1}{2} \varepsilon_0 E^2 \quad \ldots(i)$$

Energy density of magnetic field

$$u_B = \frac{1}{2\mu_0} B^2 \quad \ldots(ii)$$

Now, $$u_e = \frac{1}{2} \varepsilon_0 E^2 = \frac{1}{2} \varepsilon_0 (cB)^2 (\because E = cB)$$

$$= \frac{1}{2} \varepsilon_0 \left(\frac{1}{\sqrt{\mu_0 \varepsilon_0}}\right)^2 B^2 \qquad \left(\because c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}\right)$$

$$= \frac{1}{2\mu_0} \times B^2$$

$\therefore$ $$u_e = u_B$$

Q. 11. About 5% of the power of a 100 W light bulb is converted to visible radiation. What is the average intensity of visible radiation:

(a) at a distance of 1 m. **(b) at a distance of 10 m from the bulb?**

Assume that the radiation is emitted isotopically and neglect reflection. **[NCERT]**

Ans. Power in visible radiation, $P = \frac{5}{100} \times 100 = 5$ W

For a point source, intensity $I = \frac{P}{4\pi r^2}$, where r is distance from the source.

(a) When distance $r = 1$ m, $I = \frac{5}{4\pi (1)^2} = \frac{5}{4 \times 3.14} = 0.4$ W / m^2

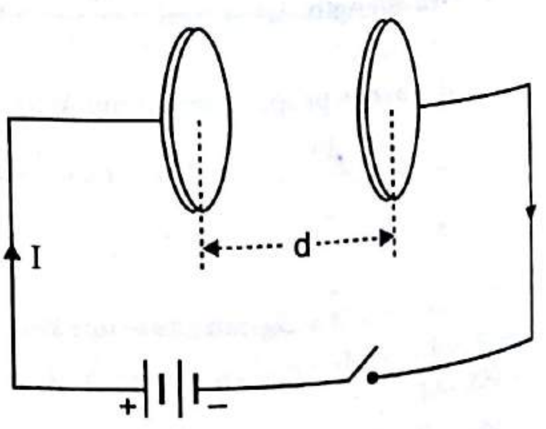
(b) When distance $r = 10$ m, $I = \frac{5}{4\pi (10)^2} = \frac{5}{4 \times 3.14 \times 100} = 0.004$ W / m^2

Q. 12. Figure represents a capacitor made of two circular plates each of radius $r = 12$ cm and separated by d = 5.0 mm. The capacitor is being charged by an external source. The charging current is constant I = 0.15 A.

(i) Calculate the rate of change of electric field between the plates.

(ii) Find the displacement current across the plates.

(iii) Is Kirchhoff's first rule valid at each plate of capacitor? Explain. **[NCERT]**



Ans. (i) Let C be the capacitance of capacitor and q the instantaneous charge on plates, then

$$q = CV$$

$$\therefore \quad \frac{dq}{dt} = C\frac{dV}{dt}$$

If E is the electric field between the plates, then $V = Ed$

$$\therefore \quad \frac{dq}{dt} = C\frac{d}{dt}(Ed)$$

i.e., $$I = C\,d\,\frac{dE}{dt}$$

$$\therefore \quad \frac{dE}{dt} = \frac{I}{Cd} = \frac{I}{\frac{\varepsilon_0 A}{d}d} = \frac{I}{\varepsilon_0 A} = \frac{I}{\varepsilon_0 \pi r^2} \quad ...(i)$$

Here, $I = 0.15$ A, $r = 12$ cm $= 12 \times 10^{-2}$ m.

$\therefore$ Rate of change of electric field between the plates

$$\frac{dE}{dt} = \frac{0.15}{8.85 \times 10^{-12} \times 3.14 \times (12 \times 10^{-2})^2} = 3.74 \times 10^{11}\ \text{Vm}^{-1}\ \text{s}^{-1}$$

(*ii*) Displacement current $I_d = \varepsilon_0 A\frac{dE}{dt} = \varepsilon_0 A\frac{I}{\varepsilon_0 A} = I$ = conduction current = 0·15 A.

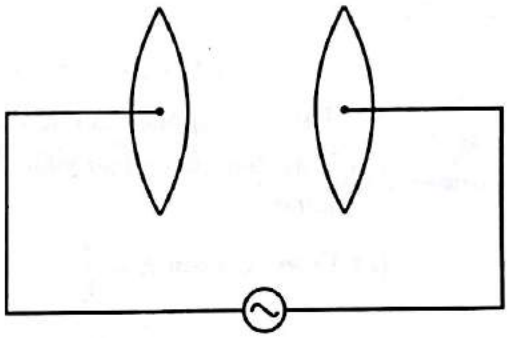
(*iii*) Yes, Kirchhoff's law holds at each plate of capacitor since displacement current is equal to conduction current.

Q. 13. A parallel plate capacitor (fig.) 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 an angular frequency of 300 rad/s.

(*a*) What is the rms value of the conduction current?

(*b*) Is conduction current equal to the displacement current?

(*c*) Determine the amplitude of magnetic field induction B at a point 3·0 cm from the axis between the plates. [*NCERT*]



Ans. Given R = 6.0 cm, $C = 100\ \text{pF} = 100 \times 10^{-12}\ \text{F} = 10^{-10}$ F, $\omega = 300$ rad/s, $V_{rms} = 230$ V

(*a*) Impedance of circuit Z = capacitance reactance $X_C = \frac{1}{\omega C}$

Root mean square current, $I_{rms} = \frac{V_{rms}}{Z} = V_{rms} \times \omega C$

$$= 230 \times 300 \times 10^{-10} = 6.9 \times 10^{-6}\ \text{A} = 6.9\ \mu\text{A}$$

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

(*c*) The whole space between the plates occupies displacement current which is equal in magnitude to the conduction current.

Magnetic field $$B = \frac{\mu_0 I r}{2\pi R^2}$$

Here $r = 3$ cm $= 3 \times 10^{-2}$ m, $R = 6$ cm $= 6 \times 10^{-2}$ m

Amplitude of displacement current = Peak value of conduction current = $I_0 = I_{rms}\sqrt{2}$

$\therefore$ Amplitude of magnetic field

$$B = \frac{\mu_0 I_0 r}{2\pi R^2} = \frac{\mu_0 I_{rms}\sqrt{2} r}{2\pi R^2}$$

$$= \frac{4\pi \times 10^{-7} \times 6.9 \times 10^{-6} \times 1.41 \times (3 \times 10^{-2})}{2\pi \times (6 \times 10^{-2})^2}$$

$$= 1.63 \times 10^{-11}\ \text{T}$$

Long Answer Questions (5 marks)

Q. 1. Given below are some famous numbers associated with electromagnetic radiation in different contents in physics. State the part of the electromagnetic spectrum to which each belongs:

(a) 21 cm (wavelength emitted by atomic hydrogen in interesteller space)

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

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

(d) 5990 Å – 5898 Å (double lines of sodium).

(e) 14.4 keV (Energy of a particular transition in ^{57}Fe nucleus associated with a famous high resolution spectroscopic method. (Massbauer Spectroscopy). *[NCERT]*

Ans. (a) 21 cm belongs to short wavelength end of radiowaves (or Hertizan waves).

(b) Wavelength $\lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{1057 \times 10^6} = 0.28\text{ m} = 28\text{ cm}$

This also belongs to short wavelength end of radiowaves.

(c) From relation $\lambda_m T = 0.29 \times 10^{-2}$ K,

$$\lambda_m = \frac{0.29 \times 10^{-2}\text{ K}}{T} = \frac{0.29 \times 10^{-2}}{2.7}$$

$$= 0.107 \times 10^{-2}\text{ m} = \mathbf{0.107\text{ cm}}$$

This corresponds to microwaves.

(d) Wavelength doublet 5990 Å – 5896 Å belongs to the visible region. These are emitted by sodium vapour lamp.

(e) From relation $E = \frac{hc}{\lambda}$,

we have $\lambda = \frac{hc}{E} \Rightarrow \lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{14.4 \times 10^3 \times 1.6 \times 10^{-19}}\text{ m} = 0.86 \times 10^{-10}\text{ m} = 0.86\text{ Å}$

It belongs to the X-ray region of electromagnetic spectrum.

Q. 2. Suppose that the electric field of an electromagnetic wave in vacuum is

$$\vec{E} = \{(3.1\text{ N/C})\cos[(1.8\text{ rad/m})y + (5.4 \times 10^6\text{ rad/s})t]\}\hat{i}$$

(a) What is the direction of propagation?

(b) What is the wavelength λ?

(c) What is the frequency ν?

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

(e) Write an expression for the magnetic field part of the wave. *[NCERT]*

Ans. (a) Wave is propagating along negative y-axis.

(b) Standard equation of wave is $\vec{E} = E_0 \cos(ky + \omega t)\hat{i}$

Comparing the given equation with standard equation, we have

$E_0 = 3.1$ N/C, $k = 1.8$ rad/m, $\omega = 5.4 \times 10^6$ rad/s.

Propagation constant $k = \frac{2\pi}{\lambda}$

$$\therefore \quad \lambda = \frac{2\pi}{k} = \frac{2 \times 3.14}{1.8}\text{ m}$$

$$= 3.49\text{ m}$$

(c) We have $\omega = 5.4 \times 10^6$ rad / s

Frequency, $\nu = \frac{\omega}{2\pi} = \frac{5.4 \times 10^6}{2 \times 3.14}$ Hz = 8.6×10^5 Hz

(d) Amplitude of magnetic field, $B_0 = \frac{E_0}{c} = \frac{3.1}{3 \times 10^8} = 1.03 \times 10^{-8}$ T

(e) The magnetic field is vibrating along Z-axis because $\vec{K}, \vec{E}, \vec{B}$ form a right handed system

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

∴ Expression for magnetic field is

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

$$= [1.03 \times 10^{-8}\ T \cos\{(1.8 \text{ rad / m})\, y + (5.4 \times 10^6 \text{ rad / s})\, t\}]\,\hat{k}$$

[C] HOTS (Higher Order Thinking Skills)

Very Short Answer Questions (1 mark)

Q. 1. Why is the orientation of the portable radio with respect to broadcasting station important? *[NCERT Exemplar]*

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

Q. 2. The charge on a parallel plate capacitor varies as $q = q_0 \cos 2\pi\nu t$. The plates are very large and close together (area = A, separation = d). Neglecting the edge effects, find the displacement current through the capacitor? *[NCERT Exemplar]*

Ans. Conduction current I_C = Displacement current I_D

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

Q. 3. A variable frequency *ac* source is connected to a capacitor. How will the displacement current change with decrease in frequency? *[NCERT Exemplar]*

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

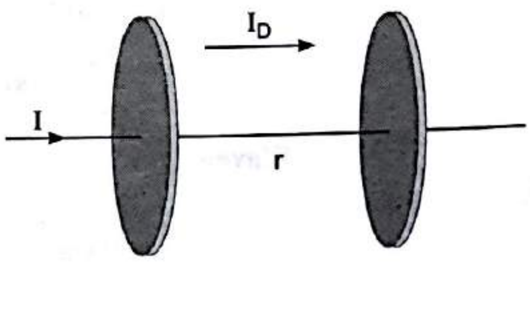
Q. 4. Professor C.V. Raman surprised his students by suspending freely a tiny light ball in a transparent vacuum chamber by shining a laser beam on it. Which property of *em* waves was he exhibiting? Give one more example of this property. *[NCERT Exemplar]*

Ans. Electromagnetic waves exert radiation pressure. Tails of comets are due to solar radiation.

Short Answer Questions (2, 3 marks)

Q. 1. Show that the magnetic field B at a point in between the plates of a parallel-plate capacitor during charging is (symbols having usual meaning). *[NCERT Exemplar]*

Ans. Let I_D be the displacement current between the parallel plate capacitor. The magnetic field at a point between the plates of capacitor at a perpendicular distance r from the axis of plates is given by



$$B = \frac{\mu_0 2 I_D}{4\pi r} = \frac{\mu_0}{2\pi r}\varepsilon_0 \frac{d\phi_E}{dt}$$

$$= \frac{\mu_0 \varepsilon_0}{2\pi r}\frac{d}{dt}(E\pi r^2) = \frac{\mu_0 \varepsilon_0 r}{2}\frac{dE}{dt}.$$

Q. 2. **Electromagnetic waves with wavelength**

(*i*) **λ_1 is used in satellite communication.**

(*ii*) **λ_2 is used to kill germs in water purifier.**

(*iii*) **λ_3 is used to detect leakage of oil in underground pipelines.**

(*iv*) **λ_4 is used to improve visibility in runways during fog and mist conditions.**

(*a*) **Identify and name the part of electromagnetic spectrum to which these radiations belong.**

(*b*) **Arrange these wavelengths in ascending order of their magnitude.**

(*c*) **Write one more application of each.** **[*NCERT Exemplar*]**

Ans. (*a*) $\lambda_1 \rightarrow$ Microwave, $\lambda_2 \rightarrow$ UV

$\lambda_3 \rightarrow$ X rays, $\lambda_4 \rightarrow$ Infrared

(*b*) $\lambda_3 < \lambda_2 < \lambda_4 < \lambda_1$

(*c*) Microwave – RADAR

UV – LASIK eye surgery

X-ray – Bone fracture identification (bone scanning)

Infrared – Optical communication

Q. 3. **In a plane electromagnetic wave, the electric field oscillates with a frequency of 2×10^{10} s^{-1} and an amplitude of 40 Vm^{-1}**

(*i*) **What is the wavelength of the wave?**

(*ii*) **What is the energy density due to electric field?**

Ans. (*i*) Wavelength $\lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{2 \times 10^{10}} = 1.5 \times 10^{-2}$ m $= 1.5$ cm

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

$$\text{Energy density due to electric field} = \frac{1}{2}\varepsilon_0 E_{rms}^2 = \frac{1}{2}\varepsilon_0 \left(\frac{E_0}{\sqrt{2}}\right)^2 = \frac{1}{4}\varepsilon_0 E_0^2$$

$$= \frac{1}{4} \times 8{\cdot}86 \times 10^{-12} \times (40)^2 = 3{\cdot}5 \times 10^{-9} \text{ J/m}^3$$

Q. 4. **The oscillating electric field of an electromagnetic wave is given by**

$$E_y = 30 \sin(2 \times 10^{11}\, t + 300\pi x) \text{ Vm}^{-1}$$

(*a*) **Obtain the value of wavelength of the electromagnetic wave.**

(*b*) **Write down the expression for oscillating magnetic field.** **[*CBSE Delhi 2008*]**

Ans. (*a*) Given equation is

$$E_y = 30 \sin(2 \times 10^{11}\, t + 300\,\pi x) \text{ Vm}^{-1}$$

Comparing with standard equation

$$E_y = E_0 \sin(\omega t + kx) \text{ Vm}^{-1}, \quad \text{we get}$$

$$E_0 = 30 \text{ Vm}^{-1}, \omega = 2 \times 10^{11} \text{ rad s}^{-1}$$

$$k = \frac{2\pi}{\lambda} = 300\,\pi \text{ m}^{-1}$$

$\therefore$ Wavelength,

$$\lambda = \frac{2\pi}{300\pi} \text{ m} = \frac{1}{150} \text{ m} = 6{\cdot}67 \times 10^{-3} \text{ m}$$

(b) The wave is propagating along X-axis, electric field is oscillating along Y-axis, so according to right hand system of $(\vec{E}, \vec{B}, \vec{K})$ the magnetic field must oscillate along Z-axis.

$$\therefore \quad B_0 = \frac{E_0}{C} = \frac{30}{3 \times 10^8} = 10^{-7} \text{ T.}$$

$\therefore$ Equation of oscillating magnetic field is

$$B_Z = B_0 \sin(\omega t + kx)\, T$$

$$\Rightarrow B_z = 10^{-7} \sin(2 \times 10^{11} t + 300\pi x)\, T$$

Q. 5. The oscillating magnetic field in a plane electromagnetic wave is given by

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

(i) Calculate the wavelength of the electromagnetic wave.

(ii) Write down the expression for the oscillating electric field. **[CBSE Delhi 2008]**

Ans. (i) Standard equation of magnetic field is

$$B_y = B_0 \sin(\omega t + kx)\, T$$

Comparing this equation with the given equation, we get

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

$$\omega = 2 \times 10^{11} \text{ rad s}^{-1}$$

$$k = \frac{2\pi}{\lambda} = 300\pi m^{-1}$$

$$\text{wavelength, } \lambda = \frac{2\pi}{300\pi} = \frac{1}{150} \text{ m}$$

(ii) $E_0 = B_0 c = 8 \times 10^{-6} \times 3 \times 10^8 = 2.4 \times 10^3 \text{ Vm}^{-1}$.

According to right hand system of $\vec{E}, \vec{B}, \vec{K}$, the electric field oscillates along negative Z-axis, so equation is

$$E_Z = -2.4 \times 10^3 \sin(2 \times 10^{11} t + 300\pi x) \text{ V m}^{-1}$$

Q. 6. Show that during the charging of a parallel plate capacitor, the rate of change of charge on each plate equals ε_0 times the rate of change of electric flux 'ϕ_E' linked with it. What is the name given to the term $\varepsilon_0 \frac{d\phi_E}{dt}$?

Ans. Charge on each plate of a parallel plate capacitor

$$q(t) = \sigma(t) A$$

But $\sigma(t) = \varepsilon_0 E(t)$

$\therefore$ $q(t) = \varepsilon_0 A E(t)$

where $\sigma(t)$ = instantaneous charge per unit area

$E(t)$ = electric field strength

But $E(t) A$ = electric flux $\phi_E(t)$

$\therefore$ $q(t) = \varepsilon_0 \phi_E(t)$

$\therefore$ Rate of change of charge

$$\frac{dq(t)}{dt} = \varepsilon_0 \frac{d\phi_E(t)}{dt}$$

$\therefore$ Rate of change of charge = ε_0 × rate of change of electron flux $|\phi_E|$

The quantity $\varepsilon_0 \frac{d\phi_E(t)}{dt}$ is named as **displacement current.**

[D] Value-based Questions

Q. 1. In the famous conversation, Rakesh Sharma, the first Indian Astronaut in space, was asked by the then Prime Minister Indira Gandhi as to how India looked from space. To which he replied '*Sare Jahan Se Achcha*' (better than the whole world).

Answer the following questions based on the above passage:

(*i*) Which mode of communication enabled the Prime Minister to speak to the Astronaut? How are these electromagnetic waves produced?

(*ii*) Which value was displayed by the Prime Minister in expressing her desire to speak to the Astronaut and in the question she asked?

(*iii*) Which two values were reflected by the Astronaut in his reply?

Ans. (*i*) Radio wave communication mode was used for the communication.

Radio waves are produced due to accelerated motion of charged particles.

(*ii*) Promotion of national prestige, technological advancement in the service of mankind.

(*iii*) Patriotism, love for the country, presence of mind.

Q. 2. Anurag fractured his leg by chance while playing. His parents took him to a doctor for treatment. The doctor advised that an X-ray of the leg needed to be done for diagnosing the problem. On seeing X-ray photograph, Anurag was amazed and excited to know that the photograph was so clear. He requested the doctor to explain how it happened. The doctor gave a brief explanation of his question happily and appreciated Anurag's nature.

Answer the following questions based on the above information:

(*i*) Which property of X-rays make it suitable for use in diagnosing and identifying the fracture in bones? Write two other uses of these rays.

(*ii*) Which two personal qualities of Anurag are reflected in his behaviour?

(*iii*) Which two values are displayed by the doctor in responding to Anurag's questions?

Ans. (*i*) The property of X-rays to easily pass through flesh but unable to pass through bones is used to take X-ray photograph.

Two other uses of X-ray are:

(*a*) Study of crystal structures.

(*b*) In engineering — for detecting cracks, faults etc.

(*ii*) Curiosity

Scientific temperament of asking questions and knowing more.

(*iii*) Readily sharing knowledge

Providing encouragement to others.