Electromagnetic Waves

basic concepts

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.

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

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

3. 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.

[Note : We also use μ for refractive index] (*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.

(*x*) Electromagnetic waves carry energy and momentun $E = \frac{hc}{\lambda}, p = \frac{U}{c} = mc$

4. 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).

5. 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	$10^{-8} - 4\times10^{-7}$	$3 \times 10^{16} - 7.5 \times 10^{14}$
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	$10^{-1} - 10^{4}$	$10^{10} - 3 \times 10^{4}$

6. 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

7. 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 items.

(*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 aircraft navigation and microwave used in homes.

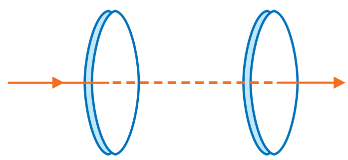
Selected NCERT Textbook Questions

Q. 1. Figure shows a capacitor made of two circular plates each of radius 12 cm and separated by 5.0 mm. The capacitor is being charged by an external source (not shown in the figure). The charging current is constant and equal to 0.15 A.

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

(*b*) Obtain the displacement current across the plates.

(*c*) Is Kirchhoff's first rule function rule valid at each plate of the capacitor? Explain.

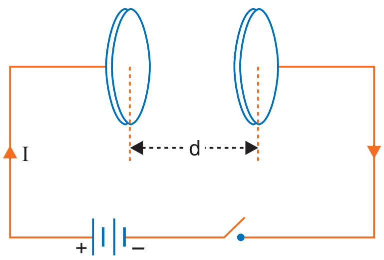


Ans. Here, $I = 0.15$ A

$r = 12 \text{ cm} = 12 \times 10^{-2}$ m

$d = 5.0 \text{ mm} = 5 \times 10^{-3}$ m

$A = \pi r^2$



(*a*) Capacitance

$$C = \frac{\varepsilon_0 A}{d} = \frac{\varepsilon_0 \pi r^2}{d}$$

$$= \frac{8.85 \times 10^{-12} \times 22 \times (12 \times 10^{-2})^2}{7 \times 5 \times 10^{-3}}$$

$$= \frac{28036.8 \times 10^{-16}}{35 \times 10^{-3}} = 801.05 \times 10^{-13} \text{ F}$$

$$= 80.1 \times 10^{-12} \text{ F}$$

$$= \mathbf{80.1 \text{ pF}}$$

Let C be the capacitance of capacitor and q the instantaneous charge on plates, then

$$q = CV$$

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

$$\therefore \quad = \frac{0.15}{80.1 \times 10^{-12}}$$

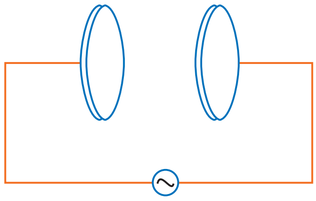
i.e., $= 0.00187 \times 10^{12} \text{ Vs}^{-1}$

$\therefore$ $= \mathbf{1.87 \times 10^9 \text{ Vs}^{-1}}$

(b) Displacement current $I_d = \varepsilon_0 A \dfrac{dE}{dt} = \varepsilon_0 A \dfrac{I}{\varepsilon_0 A} = I$ = conduction current = **0.15 A.**

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

Q. 2. 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.

Ans. Given R = 6.0 cm, C=100 pF = 1×10^{-10} F, ω = 300 rad/s, V_{rms} = 230 V

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

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

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

(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 $B = \dfrac{\mu_0 I r}{2\pi R^2}$

Here r = 3 cm = 3×10^{-2} m, R = 6 cm = 6×10^{-2} m

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

Amplitude of magnetic field

$$B = \frac{\mu_0 I_0 r}{2\pi R^2} = \frac{\mu_0 I_{rms}\sqrt{2}\, r}{2\pi R^2}$$
$$= \frac{4\pi \times 10^{-7} \times 6.9 \times 10^{-6} \times 1.41 \times (3 \times 10^{-2})}{2\pi \times (6 \times 10^{-2})^2}$$
$$= \mathbf{1.63 \times 10^{-11}\ T}$$

Q. 3. 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 ?

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 ν = 30 MHz= 30×10^6 Hz

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

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

Q. 4. A radio can tune into any station in the 7.5 MHz to 12 MHz band. What is the corresponding wavelength band ?

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

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

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

Wavelength band is from **25 m** to **40 m**.

Q. 5. 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 ?

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

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

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

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

Q. 6. Suppose that the electric field amplitude of an electromagnetic wave is E_0 = 120 N/C and that its frequency ν = 50.0 MHz. (*a*) Determine B_0, ω, k and λ (*b*) Find expressions for $\vec{E}$ and $\vec{B}$.

Ans. (*a*) We have $\frac{E_0}{B_0} = c \quad \Rightarrow \quad B_0 = \frac{E_0}{c} = \frac{120}{3 \times 10^8} = \mathbf{4 \times 10^{-7}\,T}$

$$\omega = 2\pi\nu = 2 \times 3.14 \times 50 \times 10^6 = \mathbf{3.14 \times 10^8\ rads^{-1}}$$

$$k = \frac{\omega}{c} = \frac{3.14 \times 10^8}{3 \times 10^8} = \mathbf{1.05\ radm^{-1}}$$

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

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

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

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

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

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

Q. 7. 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}]

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

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

(c) Energy density of electric field is

$$U_E = \frac{1}{2}\varepsilon_0 E^2 \qquad ...(i)$$

Energy density of Magnetic field

$$U_B = \frac{1}{2\mu_0}B^2 \qquad ...(ii)$$

where ε_0 is permittivity of free space and

μ_0 is permeability of free space

We have, $E = cB$ ...(iii)

$$\therefore \quad U_E = \frac{1}{2}\varepsilon_0 (cB)^2$$

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

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

$$\therefore \quad U_E = \frac{1}{\mu_0\varepsilon_0}\left(\frac{1}{2}\varepsilon_0 B^2\right)$$

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

$$\therefore \quad U_E = U_B$$

Q. 8. Suppose that the electric field of an electromagnetic wave in vacuum is

$$\mathbf{E = \{(3.1\ N/C)\cos(1.8\ rad/m)\ y + (5.4\times10^6\ rad/s)t\}\hat{i}}$$

(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.

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 $k = \dfrac{2\pi}{\lambda}$

$$\lambda = \frac{2\pi}{k} = \frac{2\times3.14}{1.8}\ \text{m} = \mathbf{3.49\ m}$$

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

$$\text{Frequency, } \nu = \frac{\omega}{2\pi} = \frac{5.4\times10^6}{2\times3.14}\text{Hz} = \mathbf{8.6\times10^5\ Hz}$$

(d) Amplitude of magnetic field,

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

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

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

$\therefore$ Expression for magnetic field is

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

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

Q. 9. 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 from the bulb?

(b) at a distance of 10 m?

Assume that the radiation is emitted isotopically and neglect reflection.

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

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

Multiple Choice Questions [1 mark]

Choose and write the correct option(s) in the following questions.

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

(a) visible region
(b) infrared region
(c) ultraviolet region
(d) microwave region

2. A plane electromagnetic wave travelling along X-axis has a wavelength 10.0 mm. The electric field points along Y-direction and has peak value of 30 V/m. Then the magnetic field in terms of x in metre and t in second may be expressed as [*NCERT Exemplar*]

(a) $30 \sin 200\pi \, (ct - x)$
(b) $10^{-7} \sin 200\pi \, (ct - x)$
(c) $30 \sin \frac{2\pi}{10}(ct - x)$
(d) $10^{-7} \sin \frac{2\pi}{10}(ct - x)$

3. Out of the following options which one can be used to produce a propagating electromagnetic wave?

(a) A chargeless particles
(b) An accelerating charge
(c) A charge moving at constant velocity
(d) A stationary charge

4. A linearly polarised electromagnetic wave given as $E = E_0 \hat{i} \cos(kz - \omega t)$ is incident normally on a perfectly reflecting infinite wall at $z = a$. Assuming that the material of the wall is optically inactive, the reflected wave will be given as [*NCERT Exemplar*]

(a) $E_r = -E_0 \hat{i} \cos(kz - \omega t)$
(b) $E_r = E_0 \hat{i} \cos(kz + \omega t)$
(c) $E_r = -E_0 \hat{i} \cos(kz + \omega t)$
(d) $E_r = E_0 \hat{i} \sin(kz - \omega t)$

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

(*a*) 36×10^{-5} kg m/s (*b*) 36×10^{-4} kg m/s

(*c*) 108×10^{4} kg m/s (*d*) 1.08×10^{7} kg m/s

6. A 100 Ω resistance and a capacitor of 100 Ω reactance are connected in series across a 22 V source. When the capacitor is 50% charged, the peak value of the displacement current is

(*a*) 2.2 A (*b*) 11 A

(*c*) 4.4 A (*d*) $11\sqrt{2}$ A

7. An LC circuit contains inductance L = 1μH and capacitance C = 0.01 μF. The wavelength of the electromagnetic wave generated is nearly

(*a*) 0.5 m (*b*) 5 m

(*c*) 30 m (*d*) 188 m

8. The radiowaves of wavelength 360 m are transmitted from a transmitter. The inductance of the coil which must be connected with capacitor of capacitance 3.6 μF in a resonant circuit to receive these waves will be nearly

(*a*) 10^3 H (*b*) 10^2 H

(*c*) 10^{-4} H (*d*) 10^{-8} H

9. What is the amplitude of electric field produced by radiation coming from a 100 W bulb at a distance of 4 m? The efficiency of bulb is 3.14% and it may be assumed as a point source.

(*a*) 2.42 V/m (*b*) 3.43 V/m

(*c*) 4.2×10^4 V/m (*d*) 14×10^4 V/m

10. The electric field intensity produced by the radiations coming from 100 W bulb at a 3 m distance is E. The electric field intensity produced by the radiations coming from 50 W bulb at the same distance is *[NCERT Exemplar]*

(*a*) $\frac{E}{2}$ (*b*) $2E$

(*c*) $\frac{E}{\sqrt{2}}$ (*d*) $\sqrt{2}E$

11. If E and B represent electric and magnetic field vectors of the electromagnetic wave, the direction of propagation of electromagnetic wave is along *[NCERT Exemplar]*

(*a*) E (*b*) B

(*c*) B × E (*d*) E × B

12. An electromagnetic wave travelling along z-axis is given as:
$E = E_0 \cos(kz - \omega t)$. Choose the correct options from the following; *[NCERT Exemplar]*

(*a*) The associated magnetic field is given as $B = \frac{1}{c} k \times E = \frac{1}{\omega}(\hat{k} \times E)$

(*b*) The electromagnetic field can be written in terms of the associated magnetic field as $E = c\,(B \times \hat{k})$.

(*c*) $\hat{k} . E = 0, \hat{k} . B = 0$

(*d*) $\hat{k} \times E = 0, \hat{k} \times B = 0$

13. If we want to produce electromagnetic waves of wavelength 500 km by an oscillating charge; then frequency of oscillating charge must be

(*a*) 600 Hz (*b*) 500 Hz

(*c*) 167 Hz (*d*) 15 Hz

14. Electromagnetic waves travelling in a medium having relative permeability $\mu_r = 1.3$ and relative permittivity $\varepsilon_r = 2.14$. The speed of electromagnetic waves in medium must be

(*a*) 1.8×10^8 m/s (*b*) 1.8×10^4 m/s

(*c*) 1.8×10^6 m/s (*d*) 1.8×10^2 m/s

15. Electromagnetic waves travelling in a medium has speed 2×10^8 m/s. If the relative permeability is 1, then the relative permittivity of medium must be

(*a*) 2 (*b*) 2.25

(*c*) 2.5 (*d*) 1.5

16. An electromagnetic wave of frequency 3.0 MHz passes from vacuum into a dielectric medium with relative permittivity $\varepsilon_r = 4.0$. Then

(*a*) wavelength is doubled and frequency remains unchanged

(*b*) wavelength is doubled and frequency becomes half

(*c*) wavelength is halved and frequency remains unchanged

(*d*) wavelength and frequency both remains unchanged

17. An electromagnetic wave radiates outwards from a dipole antenna, with E_0 as the amplitude of its electric field vector. The electric field E_0 which transports significant energy from the source falls off as [*NCERT Exemplar*]

(*a*) $\frac{1}{r^3}$ (*b*) $\frac{1}{r^2}$

(*c*) $\frac{1}{r}$ (*d*) remains constant

18. A plane electromagnetic wave of energy U is reflected from the surface. Then the momentum transferred by electromagnetic wave to the surface is

(*a*) 0 (*b*) $\frac{U}{c}$

(*c*) $\frac{2U}{c}$ (*d*) $\frac{U}{2c}$

19. The rms value of the electric field of light coming from the sun is 720 N/C. The average total energy density of the electromagnetic wave is :

(*a*) 4.58×10^{-6} J/m^3 (*b*) 6.37×10^{-9} J/m^3

(*c*) 1.35×10^{-12} J/m^3 (*d*) 3.3×10^{-3} J/m^3

20. A plane electromagnetic wave propagating along *x* direction can have the following pairs of *E* and *B* [*NCERT Exemplar*]

(*a*) E_x, B_y (*b*) E_y, B_z

(*c*) B_x, E_y (*d*) E_z, B_y

Answers

1. (*c*)	**2.** (*b*)	**3.** (*b*)	**4.** (*b*)	**5.** (*b*)	**6.** (*a*)
7. (*d*)	**8.** (*d*)	**9.** (*b*)	**10.** (*c*)	**11.** (*d*)	**12.** (*a*), (*b*), (*c*)
13. (*a*)	**14.** (*a*)	**15.** (*b*)	**16.** (*c*)	**17.** (*c*)	**18.** (*c*)
19. (*a*)	**20.** (*b*), (*d*)				

Fill in the Blanks [1 mark]

1. In case of electromagnetic wave, the vibrating electric field vector ($\vec{E}$) and magnetic field vector ($\vec{B}$) are mutually perpendicular to each other and both are perpendicular to the direction of ________________.

2. The current which comes into play in the region, whenever the electric field and hence the electric flux is changing with time is called ________________.

3. The orderly distribution of electromagnetic radiations according to their frequency or wavelength is called ________________.

4. The displacement current is precisely equal to the conduction current, when the two are present in different parts of the circuit. These currents are individually discontinuous, but the two currents together posses the property of ________________ through any closed circuit.

5. Electromagnetic wave is ________________ in nature as the electric and magnetic fields are perpendicular to each other and to the direction of propagation of the wave.

6. Electromagnetic waves are not ________________ by electric and magnetic waves.

7. The ________________ of electromagnetic waves does not change when it goes from one medium to another but its wavelength changes.

8. ________________ particles radiate electromagnetic waves.

9. The shortest wavelength radio waves are called ________________.

10. Ozone layer in the atmosphere plays a protective role, and hence its depletion by ____________ gas is a matter of international concern.

Answers

1. propagation **2.** displacement current **3.** electromagnetic spectrum
4. continuity **5.** transverse **6.** deflected **7.** frequency **8.** Accelerated charged
9. micro-waves **10.** chlorofluorocarbons (CFCs)

Very Short Answer Questions [1 mark]

Q. 1. How is the speed of EM-waves in vacuum determined by the electric and magnetic fields? [*CBSE Delhi 2017*]

Ans. Speed of EM waves is determined by the ratio of the peak values of electric field vector and magnetic field vector.

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

Q. 2. Do electromagnetic waves carry energy and momentum? [*CBSE (AI) 2017; 2019, (55/4/1)*]

Ans. Yes, EM waves carry energy E and momentum p. As electromagnetic waves contain both electric and magnetic fields, there is a non-zero energy density associated with it.

$$E = \frac{hc}{\lambda}$$

$$\Rightarrow \quad p = \frac{U}{c} = mc$$

Here, c = speed of EM wave in vacuum

λ = wavelength of EM wave

U = total energy transferred to the surface.

Q. 3. In which situation is there a displacement current but no conduction current? [*CBSE South 2016*]

Ans. During charging or discharging there is a displacement current but no conduction current between plates of capacitor.

Q. 4. The charging current for a capacitor is 0.25 A. What is the displacement current across its plates? [*CBSE (F) 2016*]

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

Q. 5. 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. 6. 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 ($c = 3 \times 10^8$ m/s)

This is because both are electromagnetic waves.

Q. 7. Write the expression for speed of electromagnetic waves in a medium of electrical permittivity ε and magnetic permeability μ. [*CBSE (F) 2017*]

Ans. The speed of electromagnetic waves in a material medium in given by

$$v = \frac{1}{\sqrt{\mu\varepsilon}}$$

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

Ans. Infrared radiation

Q. 12. Arrange the following electromagnetic waves in order of increasing frequency:

γ-rays, microwaves, infrared rays and ultraviolet rays. [*CBSE (F) 2014*]

Ans. Microwave < Infrared < Ultraviolet < γ-rays

Q. 13. Arrange the following electromagnetic waves in decreasing order of wavelength:

γ -rays, infrared rays, X-rays and microwaves. *[CBSE (F) 2014]*

Ans. Microwave > Infrared > X-rays > γ -rays

Q. 14. Which part of the electromagnetic spectrum is used in operating a RADAR? *[CBSE Delhi 2010; 2019 (55/2/1)]*

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

Q. 15. Why are microwaves considered suitable for radar systems used in aircraft navigation? *[CBSE Delhi 2016]*

Ans. Microwaves are considered suitable for radar systems used in aircraft navigation due to their short wavelength or high frequency.

Q. 16. 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. 17. 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.

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

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

Q. 18. 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. 19. 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.

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

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

Q. 20. 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. 21. 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. 22. It is necessary to use satellites for long distance T.V. transmission. Why? *[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. 23. Optical and radiotelescopes are built on the ground but X-ray astronomy is possible only from a satellite orbiting the earth, why? *[CBSE (AI) 2009]*

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

Q. 24. Name the electromagnetic radiations used for (*a*) water purification, and (*b*) eye surgery. [*CBSE 2018*]

Ans. (*a*) Ultraviolet rays

(*b*) Ultraviolet rays/laser

Q. 25. How are electromagnetic waves produced by accelerating charges? [*CBSE 2019 (55/2/1)*]

Ans. Accelerated charge produces an oscillating electric field which produces an oscillating magnetic field, which is a source of oscillating electric field, and so on. Thus electromagnetic waves are produced.

Q. 26. 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

$$I_d = \varepsilon_0 \frac{d\phi_E}{dt} \quad \text{where } \phi_E \text{ is the electric flux.}$$

Q. 27. 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. 28. Why is the orientation of the portable radio with respect to broadcasting station important? [*NCERT Exemplar*] [*HOTS*]

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

Q. 29. The charge on a parallel plate capacitor varies as $q = q_0 \cos 2\pi \upsilon t$. 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*] [*HOTS*]

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

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

Q. 31. 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*] [*HOTS*]

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

Q. 32. How are infrared waves produced?

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

Short Answer Questions–I [2 marks]

Q. 1. State two properties of electromagnetic waves. How can we show that EM waves carry momentum? [*CBSE South 2016*]

Ans. Properties of electromagnetic waves:

(*i*) Transverse nature

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

(*iii*) Same speed in vacuum for all waves

(*iv*) No material medium required for propagation

(*v*) They get refracted, diffracted and polarised

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

Q. 2. How does Ampere-Maxwell law explain the flow of current through a capacitor when it is being charged by a battery? Write the expression for the displacement current in terms of the rate of change of electric flux. [*CBSE Delhi 2017*]

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

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

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, $\oint \vec{B}.\vec{dl} = \mu_0 I_C$.

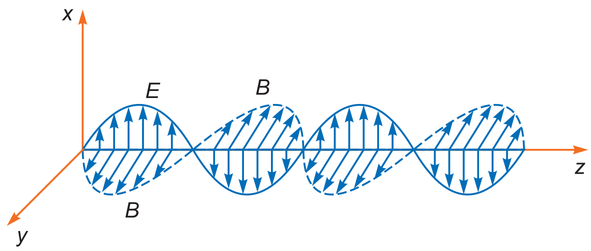
(*ii*) In large region of space, where there is no conduction current, but there is only a displacement current due to time varying electric field (or flux). So, $\phi \vec{B}.\vec{dl} = \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$.

Q. 4. (*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, Delhi 2016*]

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.

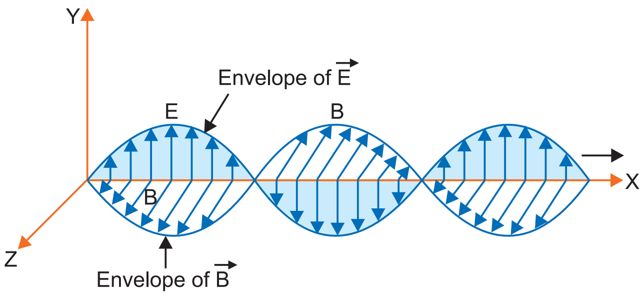


Q. 5. **(a) An EM wave is travelling in a medium with a velocity $\vec{v} = v\hat{i}$. Draw a sketch showing the propagation of the EM wave, indicating the direction of the oscillating electric and magnetic fields.**

(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 $\vec{E} \times \vec{B}$

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



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

Q. 6. **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. 7. **(i) How are infrared waves produced? Write their one important use.**

(ii) The thin ozone layer on top of the stratosphere is crucial for human survival. Why? [*CBSE East 2016; 2019 (55/4/1)*]

Ans. (i) Infrared waves are produced by hot bodies and molecules.

Important use:

(a) To treat muscular strains (b) To reveal the secret writings on the ancient walls (c) For producing dehydrated fruits (d) Solar heater (e) Solar cooker (*Any one*)

(ii) Ozone layer protects us from harmful UV rays.

Q. 8. **(i) Which segment of electromagnetic waves has highest frequency? How are these waves produced? Give one use of these waves.**

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

Ans. (i) Gamma rays have the highest frequency. These are produced during nuclear reactions and also emitted by radioactive nuclei. They are used in medicine to destroy cancer cells.

(ii) Ultraviolet rays lie near the high frequency end of visible part of EM spectrum. They are used to sterlise drinking water and surgical instruments. Exposure to UV radiation induces the production of more melanin, causing tanning of the skin.

Q. 9. 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, 2019 (55/2/3)*]

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. 10. Identify the electromagnetic waves whose wavelengths vary as

(*a*) 10^{-12}m < λ < 10^{-8} m **(*b*) 10^{-3} m < λ < 10^{-1} m**

Write one use for each. **[*CBSE (AI) 2017*]**

Ans. (*a*) **X-rays:** Used as a diagnostic tool in medicine and as a treatment for certain forms of cancer.

(*b*) **Microwaves:** Used in radar systems for aircraft navigation.

Q. 11. Identify the electromagnetic waves whose wavelengths lie in the range

(*a*) 10^{-11}m < λ < 10^{-8} m **(*b*) 10^{-4} m < λ < 10^{-1} m**

Write one use of each. **[*CBSE (AI) 2017*]**

Ans. (*a*) X-rays / Gamma rays

(*b*) Infrared / Visible rays / Microwaves

(*i*) X-rays are used as a diagnostic tool in medicine.

(*ii*) Gamma rays are used in medicine to destroy cancer cells.

(*iii*) Infrared are used in green houses to warm plants.

(*iv*) Visible rays provide us information about the world.

(*v*) Microwaves are used in RADAR system for aircraft navigation.

Q. 12. 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? **[*HOTS*]**

Ans. (*i*) Wavelength

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

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

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

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

$$= \frac{1}{4} \times 8.86 \times 10^{-12} \times (40)^2 = \mathbf{3.5 \times 10^{-9} \text{ J/m}^3}$$

Q. 13. (*a*) Why are infra-red waves often called heat waves? Explain.

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

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

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

Short Answer Questions–II [3 marks]

Q. 1. How are electromagnetic waves produced? What is the source of energy of these waves? Write mathematical expressions for electric and magnetic fields of an electromagnetic wave propagating along the *z*-axis. Write any two important properties of electromagnetic waves.

[*CBSE North 2016*]

Ans. EM waves are produced by oscillating charged particle.

Mathematical expression for electromagnetic waves travelling along *z*-axis:

$E_x = E_0 \sin (kz - \omega t)$ and [For electric field]

$B_y = B_0 \sin (kz - \omega t)$ [For magnetic field]

Properties

(*i*) Electromagnetic waves have oscillating electric and magnetic fields along mutually perpendicular directions.

(*ii*) They have transverse nature.

Q. 2. Arrange the following electromagnetic waves in the order of their increasing wavelength:

(*a*) γ-rays **(*b*) Microwaves**

(*c*) X-rays **(*d*) Radiowaves**

How are infra-red waves produced? What role does infra-red radiation play in (*i*) maintaining the earth's warmth and (*ii*) physical therapy? **[*CBSE Panchkula 2015*]**

Ans. γ-rays < X-rays < Microwaves < Radiowaves

Infra red rays are produced by the vibration of atoms and molecules.

(*i*) **Maintaining Earth's Warmth:** Infrared rays are absorbed by the earth's surface and reradiated as longer wave length infrared rays. These radiations are trapped by green house gases such as CO_2 and maintain earth's warmth.

(*ii*) **Physical Therapy:** Infrared rays are easily absorbed by water molecules present in body. After absorption, their thermal motion increases causing heating which is used as physical therapy.

Q. 3. 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

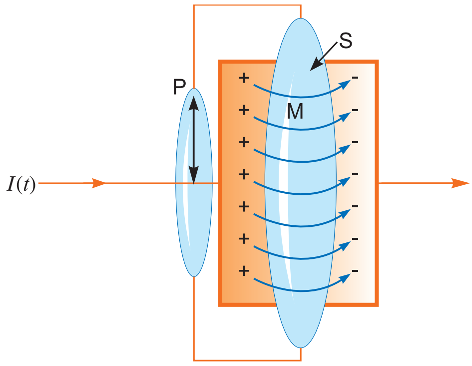
$$I_d = \varepsilon_0 \frac{d\phi_E}{dt}$$

and $I_d = I_c$ at all instants.

Q. 4. Why does a galvanometer when connected in series with a capacitor show a momentary deflection, when it is being charged or discharged?

How does this observation lead to modifying the Ampere's circuital law? Hence write the generalised expression of Ampere's law. **[*CBSE (F) 2015*]**

Ans. During charging or discharging of the capacitor, displacement current between the plates is produced. Hence, circuit becomes complete and galvanometer shows momentary deflection.



According to Ampere's circuital Law

$$\oint \vec{B}.\vec{dl} = \mu_0 I$$

At surface P, $\oint \vec{B}.\vec{dl} = \mu_0 I_c$

At surface S, $\oint \vec{B}.\vec{dl} = 0$

$\therefore$ $\oint_p \vec{B}.\vec{dl} \neq \oint_s \vec{B}.\vec{dl}$

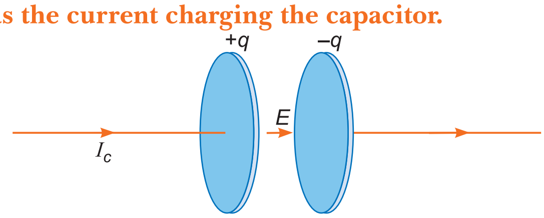
This contradicts Ampere's circuital law. This law must be missing something. Hence the law needs modification.

Modified form of Ampere's circuital law

$$\oint \vec{B}.\vec{dl} = \mu_0 \left[I_c + \varepsilon_0 \frac{d}{dt}\phi_E \right]$$

Q. 5. 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, $$I_c = \frac{dq}{dt} \qquad ...(i)$$

According to Maxwell, displacement current between plates,

$$I_d = \varepsilon_0 \frac{d\phi_E}{dt}, \text{ where } \phi_E = \text{Electric flux} \qquad ...(ii)$$

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

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

So $$I_d = \varepsilon_0 \frac{d}{dt}\left(\frac{q}{\varepsilon_0}\right) \Rightarrow I_d = \frac{dq}{dt} \qquad ...(iii)$$

From equation (*i*) and (*iii*),

Both conduction current and displacement current are equal.

Q. 6. Write the expression for the generalised form of Ampere's circuital law. Discuss its significance and describe briefly how the concept of displacement current is explained through charging/discharging of a capacitor in an electric circuit. **[*CBSE Allahabad 2015*]**

Ans. The generalisation in Ampere's circuital law was modified by Maxwell, as

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

$$= \mu_0 I_c + \mu_0 I_d = \mu_0 I_c + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$$

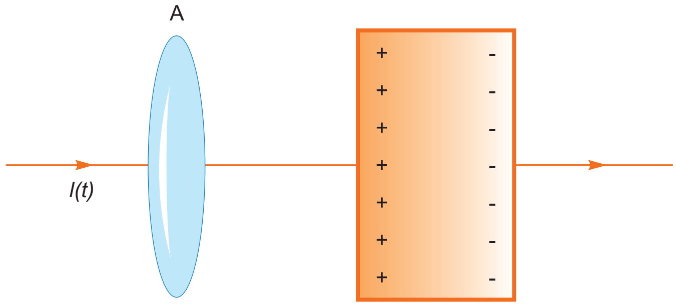
where $I_d = \varepsilon_0 \dfrac{d\phi_E}{dt}$ is displacement current.

Significance: This expression signifies that the source of magnetic field is not just due to the conduction current in the metallic conductors, but also due to the time rate of change of electric flux called displacement current.

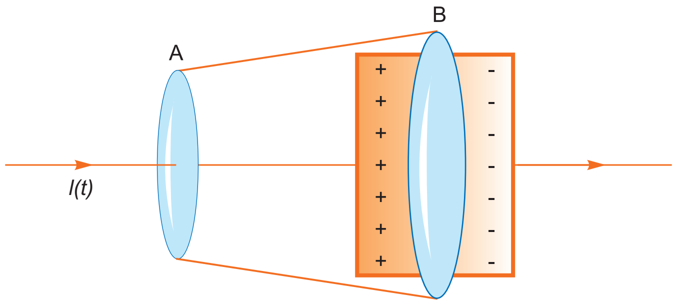
During charging and discharging of a capacitor, electric field between the plates will change. Hence there will be a change in electric flux, called displacement current, between the plates.

Q. 7. 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 capacitor C, a time varying current $I(t)$ flows through the conducting wire, so on applying Ampere's circuital law (for loop A) $\oint \vec{B}.\vec{dl} = \mu_0 I(t)$ ... (*i*)



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

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

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

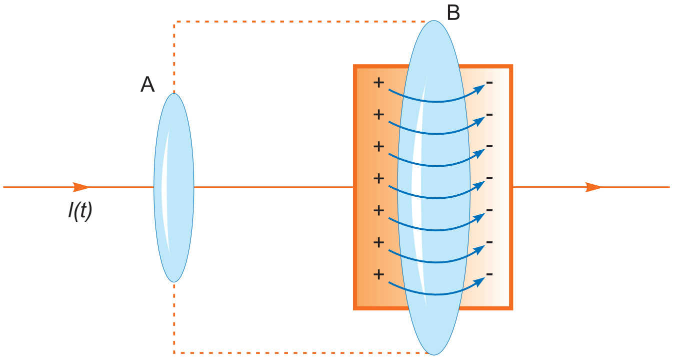
If surfaces A and B forms a tiffin box, and electric field $\vec{E}$ is passing through the surface (B); constitute an electric flux

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

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

$$\oint \vec{B}.\vec{dl} = \mu_0 I_c + \mu_0 I_d = \mu_0 I_c + \mu_0 \varepsilon_0 \frac{d\phi}{dt}$$

Q. 8. **(*a*) Which one of the following electromagnetic radiations has least frequency: UV radiations, *X*-rays, Microwaves?**

(*b*) How do you show that electromagnetic waves carry energy and momentum?

(*c*) Write the expression for the energy density of an electromagnetic wave propagating in free space. [*CBSE Bhubaneswar 2015*]

Ans. (*a*) Microwave

(*b*) When a charge oscillates with some frequency. It produces an oscillating electric field and magnetic field in space. So, an electromagnetic wave is produced.

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

Hence energy associated with the EM wave comes at the expense of the energy of the source.

If the em wave of energy U strikes on a surface and gets completely absorbed, total momentum delivery to the surface is $p = \frac{U}{E}$.

Hence em wave also carry momentum.

(*c*) The EM wave consists of oscillating electric and magnetic fields, So net energy density of EM wave is

$$U = U_E + U_B$$

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

Q. 9. **(*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 atmosphere and less diffraction in the atmospheric layers. So these waves are suitable for the radar systems used in aircraft navigation.

Q. 10. Name the parts of the electromagnetic spectrum which is

(*i*) suitable for radar systems used in aircraft navigation.

(*ii*) used to treat muscular strain.

(*iii*) used as a diagnostic tool in medicine.

Write in brief, how these waves can be produced. [*CBSE Delhi 2015*]

Ans. (*i*) Microwave, (*ii*) Infrared, (*iii*) X-rays

Microwave are produced by special vacuum tubes, like klystorms, magnetrons and gunn diodes.

Infrared are produced by the vibrating molecules and atoms in hot bodies.

X-rays are produced by the bombardment of high energy electrons on a metal target of high atomic weight (like tungsten).

Q. 11. (*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.

[*CBSE Central 2016*]

Ans. (*i*) (*a*) Microwaves

(*b*) X-rays

(*ii*) Due to conduction current in the connecting wires and the production of displacement current between the plates of capacitor on account of changing electric field.

Current inside the capacitor is given by

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

Q. 12. 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 infrared rays and get heated up.

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

Q. 13. 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, $p = \dfrac{U}{c}$

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.

Q. 14. 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. 15. 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 $\varepsilon_0 \dfrac{d\phi_E}{dt}$? [*HOTS*]

Ans. Charge on each plate of a parallel plate capacitor

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

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

$\therefore$ $q(t) = \varepsilon_0\, AE\,(t)$

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

$E(t)$ = electric field strength

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

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

$\therefore$ Rate of change of charge

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

$\therefore$ Rate of change of charge = $\varepsilon_0 \times$ rate of change of electron flux $|\phi_E|$

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

Self-Assessment Test

Time allowed: 1 hour **Max. marks: 30**

1. Choose and write the correct option in the following questions. **(3 × 1 = 3)**

(*i*) The ratio of contributions made by the electric field and magnetic field components to the intensity of an electromagnetic wave is

(*a*) $c : 1$ (*b*) $c^2 : 1$

(*c*) $1 : 1$ (*d*) $\sqrt{c} : 1$

(*ii*) The quantity $\sqrt{\mu_0 \varepsilon_0}$ represents

(*a*) speed of sound (*b*) speed of light in vacuum

(*c*) speed of electromagnetic waves (*d*) inverse of speed of light in vacuum

(*iii*) The ratio of amplitude of magnetic field to the amplitude of electric field for an electromagnetic wave propagating in vacuum is equal to

(*a*) the speed of light in vacuum

(*b*) reciprocal of speed of light in vacuum

(*c*) the ratio of magnetic permeability to the electric susceptibility of vacuum

(*d*) unity

2. Fill in the blanks. **(2 × 1 = 2)**

(*i*) Displacement current is the electric current which flows in the gap between the plates of capacitor during its ______________, which originates due to time varying electric field in the space between the plates of capacitor.

(*ii*) The basic different between various types of electromagnetic waves lies in their ______________ since all of them travel through vacuum with the same speed.

3. In which directions do the electric and magnetic field vectors oscillate in an electromagnetic wave propagating along the x-axis? **1**

4. Name the electromagnetic radiation to which waves of wavelength in the range of 10^{-2} m belong. Give one use of this part of electromagnetic spectrum. **1**

5. Name the electromagnetic radiation which can be produced by klystron or a magnetron valve. **1**

6. The oscillating electric field of an electromagnetic wave is given by

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

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

(*b*) Write down the expression for oscillating magnetic field. **2**

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

$$B_z = (8 \times 10^{-6}) \sin [2\times10^{11}t + 300\pi x] \text{ T}$$

(*i*) Calculate the wavelength of the electromagnetic wave.

(*ii*) Write down the expression for the oscillating electric field. **2**

8. How are microwaves produced? Write their two important uses. **2**

9. Answer the following questions :

(*a*) Optical and radio telescopes are built on the ground while X-ray astronomy is possible only from satellites orbiting the Earth. Why?

(*b*) The small ozone layer on top of the stratosphere is crucial for human survival. Why? **2**

10. 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. **3**

11. How are electromagnetic waves produced? What is the source of the energy carried by a propagating electromagnetic wave?

Identify the electromagnetic radiations used

(*i*) in remote switches of household electronic devices; and

(*ii*) as diagnostic tool in medicine. **3**

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

(*b*) Prove that the average energy density of the oscillating electric field is equal to that of the oscillating magnetic field. **3**

13. (*a*) A parallel plate capacitor is being charged by a time varying current. Explain briefly how Ampere's circuital law is generalized to incorporate the effect due to the displacement current.

(*b*) Find the wavelength of electromagnetic waves of frequency 6×10^{12} Hz in free space. Give its two applications. **5**

Answers

1. (*i*) (*c*) (*ii*) (*d*) (*iii*) (*b*)

2. (*i*) charging (*ii*) wavelengths or frequencies

6. (*a*) 6.67×10^{-3} m (*b*) $10^{-7} \sin (2 \times 10^{11}t + 300\pi x)$ T

7. (*i*) 6.67×10^{-3} m (*ii*) $2.4 \times 10^{3} \sin (2 \times 10^{11}t + 300\pi x)$ Vm^{-1}