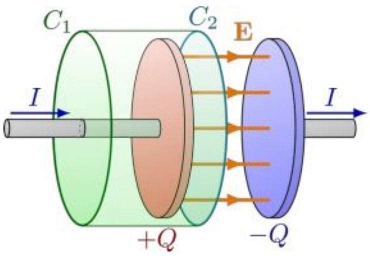
CHAPTER 8
ELECTROMAGNETIC WAVES

DISPLACEMENT CURRENT

Maxwell in 1864, showed that Ampere's circuital law is logically inconsistent. Consider a parallel plate capacitor, which is being charged. Consider two loops C_1 and C_2 parallel to the plates as shown in figure.



For loop C_1, a current i(t) is flowing through it, hence Ampere's circuital law for loop C_1 gives

$$\oint_{c_1} \vec{B}.\vec{dl} = \mu_0 i_c \quad ....(1)$$

Since the loop C_2 lies in the region between the plates of the capacitor, no current flows in this region. Hence Ampere's circuital law for loop C_2 gives

$$\oint_{c_1} \vec{B}.\vec{dl} = 0 \quad ....(2)$$

These two integrals in eqns (1) and (2) are taken on either sides of the plate P_1. So they must be consistent but we find that they are not consistent.

To remove this inconsistency Maxwell introduced an additional current $i_d = \epsilon_0 \frac{d\phi_E}{dt}$ called **displacement current**, where ϕ_E is the electric flux through the loop C.

Thus Maxwell modified Ampere's law into the form

$$\oint_{c_1} \vec{B}.\vec{dl} = \mu_o (i_c + \epsilon_0 \frac{d\phi_E}{dt})$$

(Or) $$\oint_{c_1} \vec{B}.\vec{dl} = \mu_o (i_c + i_d)$$

Where, i_C is conduction current. Its value is zero in vacuum and dielectrics and non-zero in conductors. i_d is the displacement current. It is zero in conductors and non-zero in vacuum and dielectrics

Thus the **Displacement current** is the current which comes into play in vacuum or dielectric when electric field is changing with time .

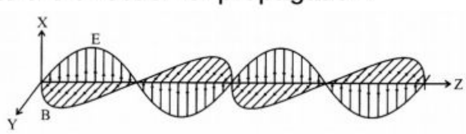
MAXWELL'S EQUATIONS IN VACUUM

1.	$\oint \vec{E}.\vec{da} = \frac{q}{\epsilon_0}$	Gauss's law in electricity
2.	$\oint \vec{B}.\vec{da} = 0$	Gauss's law in magnetism
3.	$\oint \vec{E}.\vec{dl} = \frac{-d\phi_B}{dt}$	Faraday's law
4.	$\oint_{c_1} \vec{B}.\vec{dl} = \mu_o (i_c + \epsilon_0 \frac{d\phi_E}{dt})$	Ampere-Maxwell law

ELECTROMAGNETIC WAVES

From Maxwell's 3rd eqn, a time varying magnetic flux produces a magnetic field and from 4th equation a time varying magnetic flux gives rise to an electric field. Therefore Maxwell suggested that a wave of electric and magnetic fields exists. Such a wave is called an electromagnetic wave.

PROPERTIES OF ELECTROMAGNETIC WAVES

1.	An electromagnetic wave consists of a varying electric field and a varying magnetic field of the same frequency and the same phase.
2.	The e.m waves are transverse in nature with the electric and magnetic fields perpendicular to the direction of propagation.  $E_x = E_{0x} \sin(kz - \omega t)$ $B_y = B_{0y} \sin(kx - \omega t)$ Where $k = \frac{2\pi}{\lambda}$ and $\omega = \frac{2\pi}{T}$
3.	The amplitudes of Electric field and magnetic field are different. $E_0 = c B_0$
4.	The speed of electromagnetic wave through vacuum is $\frac{1}{\sqrt{\mu_0 \epsilon_o}}$ and in a medium $\frac{1}{\sqrt{\mu \epsilon}}$
5.	Electromagnetic waves are produced by accelerated charges
6.	E.m.waves do not need a material medium for their propagation

Problem 1 (Example 8.1 NCERT)

A plane electromagnetic wave of frequency 25 MHz travels in free space along the x-direction.

At a particular point in space and time, electric field **E** = 6.3 ĵ V/m. What is **B** at this point?

Solution

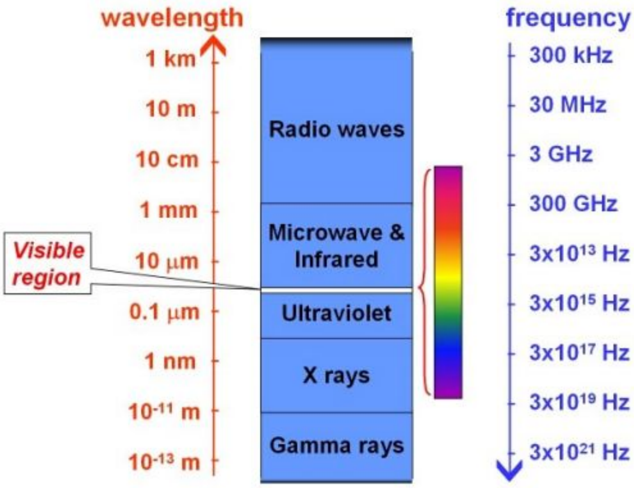
$$B=\frac{E}{c} \Rightarrow B=\frac{6.3}{3x\,10^{8}}=2.1\,x\,10^{-8}T$$

Direction: Along z direction since the **E** is in y direction and x is the direction of propogation

Therefore $B=6.3=2.1\,x\,10^{-8}\hat{k}\,T$

ELECTROMAGNETIC SPECTRUM

orderly arrangement of electromagnetic waves from lower frequency (radio waves) to higher frequency (gamma rays) .



Mnemonic: Red Man In Violet Uniform X Gun

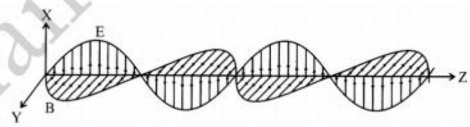
ELECTROMAGNETIC WAVES AND USES

EM Waves	Uses
Radio waves	communication using radio, T V, cellular phone etc
Microwaves	Used in RADAR, Satellite communication, microwave oven
Infrared Radiation	Infrared camera, physiotherapy, for determination of molecular structure.
Visible light	Humans see objects
Ultraviolet Radiations:	Produce vitamin D in our skin. Used in water purifiers, used to sterilize bottle waters..
X-Rays	To take X ray photograph of human body, to study crystal structure
Gamma Rays	Study of nuclear Structure, for the treatment of Cancer, to sterilize surgical Instruments, to detect cracks in underground metal pipes etc.

PRODUCTION AND DETECTION OF EM WAVES

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

PREVIOUS QUESTIONS

1.	A typical plane electromagnetic wave propagating along the Z direction is shown in figure. 	
a)	Write the equation for electric and magnetic fields.	1
b)	Write the methods of production of radio waves and microwaves. Write any one use of these wave	2
2.	The electromagnetic waves used in LASIK eye surgery is (i) micro waves (ii) infra-red waves (iii) ultraviolet rays (iv) gamma rays	1
3.a)	The current due to time varying electric field is called	1
b)	An electromagnetic wave travels in free space with a velocity of 3 x 10 ^{8} m/s. At a particular point in space and time, magnitude of intensity of electric field is 6.3 V/m. What is magnitude of magnetic field at this point ?	2
4.	Relation between velocity of light (c), permeability of free space (μ_0), permittivity of free space (ϵ_0) is .... (a) $\frac{1}{\mu_0\,\epsilon_o}$ (b) $\frac{1}{\sqrt{\mu_0\,\epsilon_o}}$	1

	(c) $\mu_0 \epsilon_o$ (d) $\sqrt{\mu_0 \epsilon_o}$	
5.	X-rays were discovered by...............in 1895. (a) Roentgen (b) J.J. Thompson (c) William Crookes (d) Rutherford	1
6.	How Maxwell modified Ampere's law ?	2
7.	Briefly explain the electromagnetic spectrum.	3
8.	The frequencies of gamma rays, ultraviolet rays, and x rays are ν_1, ν_2, ν_3 respectively. Then, (i) $\nu_1 = \nu_2 = \nu_3$ (ii) $\nu_1 > \nu_3 > \nu_2$ (iii) $\nu_1 > \nu_2 > \nu_3$ (iv) $\nu_3 > \nu_2 > \nu_1$	1