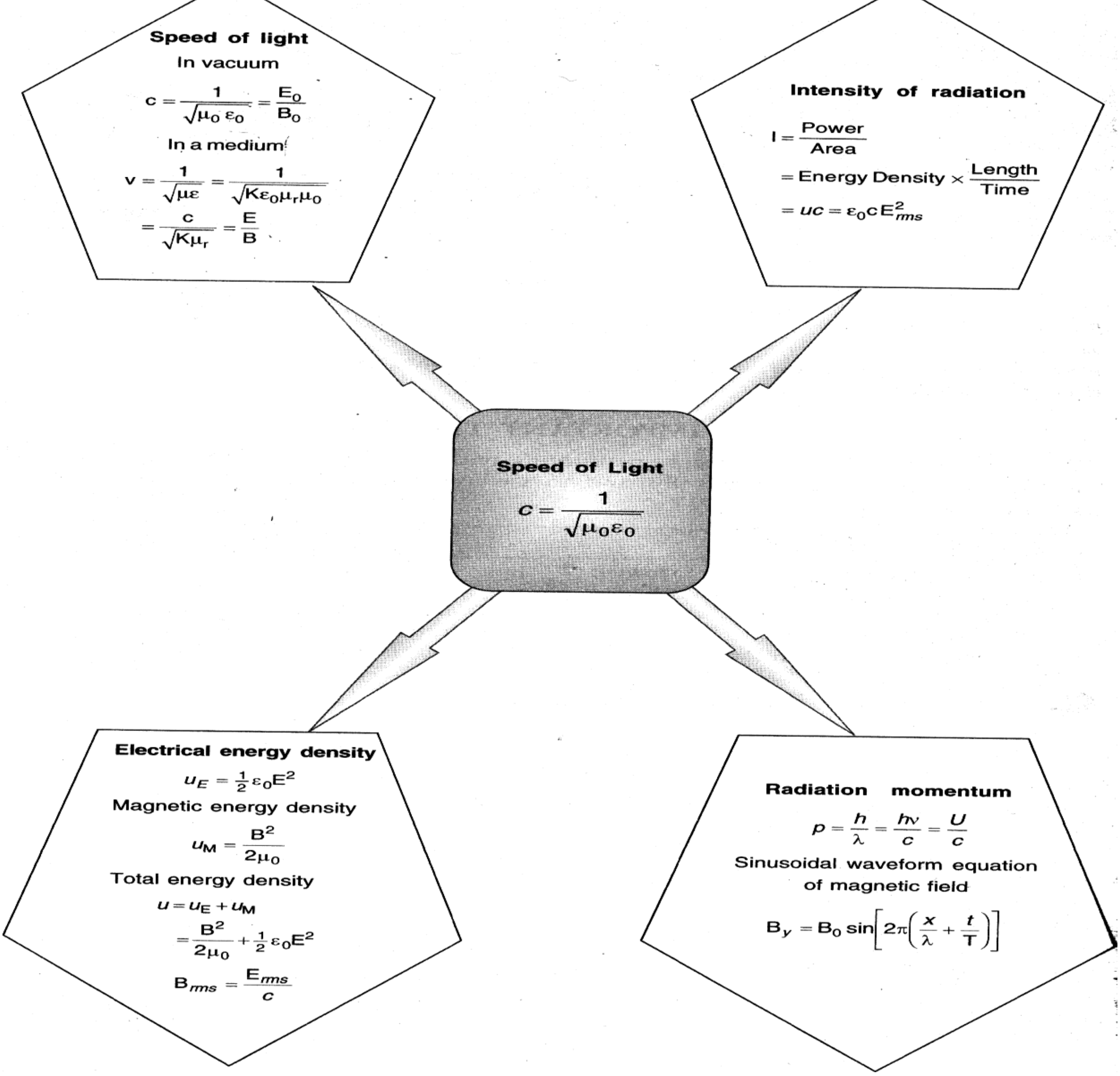
FORMULA AT A GLANCE



<u>Electromagnetic Waves:-</u>

- <u>Definition:</u> When electric and magnetic fields vary at right angles to each other as well as perpendicular to the direction of propagation of the wave.
- The varying EF produces a varying MF & vice-versa.
- The existence of em waves was predicted by Maxwell in the year 1864.

Properties of EM waves:-

- The EF & MF are always perpendicular to the direction of the travel of the wave. Therefore it is a transverse wave. Also EF is also perpendicular to MF.
- An accelerated charge is the source of electromagnetic wave.
- The cross product of EF & MF gives the direction of travel of the wave.
- They do not need any medium for propagation.
- The speed of em waves in any medium is given by,

$$\boxed{v = 1/\sqrt{\mu\varepsilon}}$$

Where,

μ - magnetic permeability

ε - electrical permittivity of the medium

For vacuum,

$$\boxed{c = 1/\sqrt{\mu_0\varepsilon_0}}$$

$= 3 * 10^8$ m/s

- The phase difference between EF & MF is zero. Therefore they attain maxima and minima at the same time.
- The amplitudes of EF & MF in free space are related to each other by,

$$\boxed{c = E/B}$$

$\Rightarrow \quad E \propto B$

- The energy in em waves is equally divided between EF & MF. Average electric energy density: $u_E = \varepsilon_0 E^2/2$
  Average magnetic energy density: $u_M = B^2/2\mu_0$

  The instantaneous energy flow ie. energy per unit time per unit area is given by,

$$\boxed{u = EB/\mu_0}$$

- The EF vector is responsible for the optical effects of an em wave and hence is also called light vector.
- The em waves are not affected by EF's & MF's.

Production of em waves:-

- EM waves arise due to varying MF producing a varying EF or vice versa.
- An accelerating charge can produce em waves.
- To produce good em waves high frequency electric oscillations should be setup in an open circuit.
- The Hertz setup for producing em waves involves:

- ❖ Two large square metal plates connected to two highly polished metallic spheres through thick copper wires.
- ❖ A high potential difference is applied with the help of an induction coil due to which the air gap between the two spheres gets ionized and electric spark is produced and em waves of high frequency is radiated.
- ❖ The two plates act as capacitor and connecting wires provides low inductance.

The frequency of the waves produced is given by the expression

$$f = 1/2\pi\sqrt{LC}$$

The dimensions of the setup can regulate the frequency of the waves produced.

- ❖ The receiver or detector is made up of conducting wire and has a spark gap.
- ❖ The variable EF induced by variable MF causes the spark to appear in the narrow gap.
- ❖ The position of the detector must be such that the MF produced by the oscillating charges is perpendicular to the plane of the loop.

Electromagnetic Spectrum: -

- ➢ Definition: The orderly distribution of em waves according to their wavelength or frequency is called an electromagnetic spectrum.
- ➢ The boundaries separating the different regions are not sharply defined. The approximate limits for the em waves of different regions are shown below:

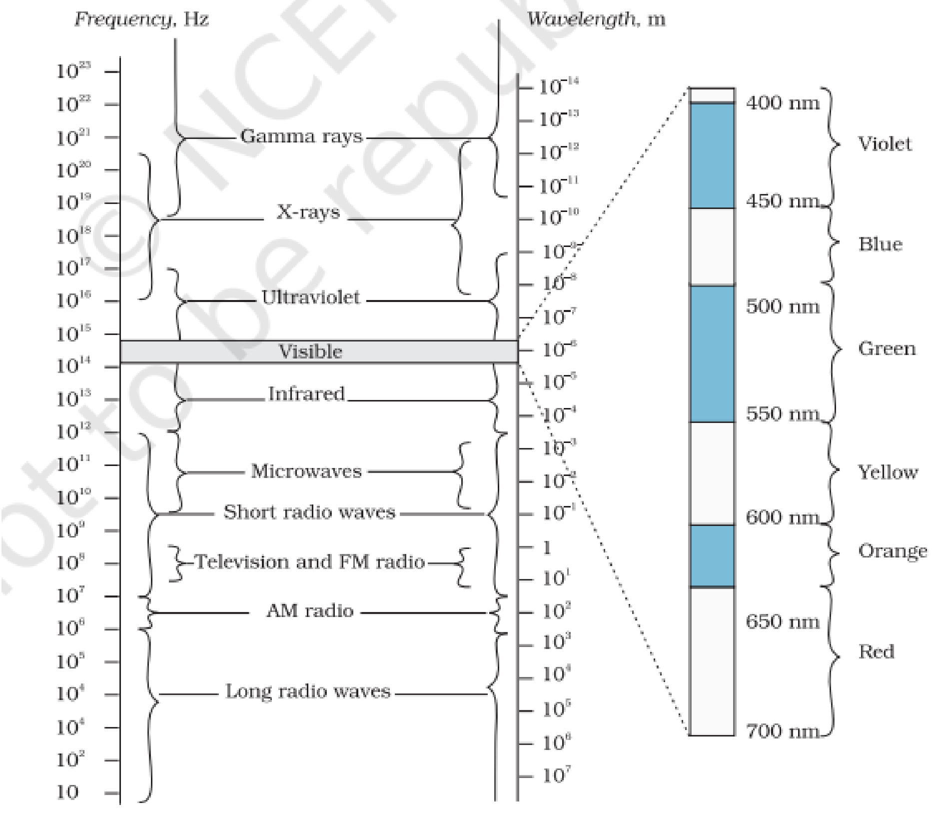


FIGURE 8.5 The electromagnetic spectrum, with common names for various part of it. The various regions do not have sharply defined boundaries.

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TABLE 8.1 DIFFERENT TYPES OF ELECTROMAGNETIC 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-

Information about the different em waves:-

- Radio waves:
  - They are produced by the accelerated motion of charges in conducting wires.
  - Uses: 1) They are used in radio and TV communication systems.
    2) Cellular phones use radio wave to transmit voice communication in the ultrahigh frequency band.
  - Frequency range: 500 kHz to 1000 MHz

- Microwaves:
  - They are produced by special vacuum tubes such as klystrons, magnetrons & Gunn diodes.
  - They are short wavelength radio waves.
  - Uses: 1) They are used in radar systems for aircraft navigation and speed guns.
    2) They are also used in microwave ovens.
  - Frequency range: in the gigahertz range

- Infrared waves:
  - They are produced by hot bodies and molecules.
  - They are sometimes referred to as heat waves.
  - Uses: 1) IR lamps are used in physical therapy.
    2) IR radiation plays an important role in maintaining the average temperature of the earth through the greenhouse effect.
- Visible light:
  - It is the only part of the spectrum detected by the human eye.
  - Uses: 1) vision.
  - Frequency range: 4 x 1014 Hz to 7 x 10^{14} Hz

- Wavelength range: 700 – 400 nm.

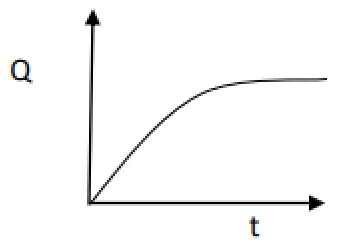
- Ultraviolet light:
  - UV radiation is produced by special lamps and very hot bodies.
  - Wavelength range: 400nm – 0.6nm
  - The sun is an important source of UV rays.
  - Harmful effects: 1) Causes cancer.
  - Most of the UV rays are absorbed by the ozone layer present at an altitude of about 30-50km above sea level.
- X-Rays:
  - X-Rays can be generated by the bombardment of a metal target by high energy electrons.
  - Uses: 1) It is used as a diagnostic tool in medicine and as a treatment for certain forms of cancer.
  - Wavelength range: 10nm to 10^{-4} nm.
- Gamma rays:
  - They are produced in nuclear reactions and are also emitted by radioactive nuclei.
  - They are highly penetrating rays.
  - Wavelength range: 10^{-10} to 10^{-14}

ELECTROMAGNETIC WAVES:

Faraday's theory suggests the existence of electric due to a time-varying magnetic field. According to Maxwell, a time varying electric field produces a magnetic field also. Such a time-varying electric field is always present around an accelerated particle. Thus electric and magnetic field are present near such an electric charge. So, Maxwell's theory says: accelerated charged particles produce e.m. waves.

DISPLACEMENT CURRENT

It is the current due to the time-varying electric field present in a given region. Consider the process of charging of a capacitor. The variation of charge with time in a capacitor can be shown as:



During charging, instantaneous current is present in the conductor. At the same time the electric field present between the plates of the capacitor keeps changing. By Maxwell, leads to 'displacement current'. Applying Ampere's circuital law to the loops L1 and L2, as shown,

we get On L1, $\int B.dl = \mu_0 I$ and on L2 $\int B.dl = 0$

Thus, the magnetic field is different for the two loops. This contradiction was removed by Maxwell by the modification of Ampere's circuital law as follows:

$\int B\,dl = \mu_0 (I_c+I_d)$, where $I_d = \varepsilon_0\, d\varphi_E/dt$ called ' displacement current'.

Here the displacement current is due to the varying charges accumulated on the plates of the capacitor. Continuity of displacement and conduction currents The above equation is valid in all circumstances only if the conduction and displacement currents are equal. This can be shown mathematically as follows:

Displacement current $I_d = \varepsilon_0 d\varphi_E/dt = \varepsilon_0 d(EA)/dt = \varepsilon_0 Ad\ ((\sigma/\varepsilon_0)/dt) = Ad\ ((Q/A)/dt)$

$= dQ/dt = I$, the conduction current.

MAXWELL'S EQUATIONS IN VACUUM

1. $\oint \mathbf{E}\cdot d\mathbf{A} = Q/\varepsilon_0$ (Gauss's Law for electricity)
2. $\oint \mathbf{B}\cdot d\mathbf{A} = 0$ (Gauss's Law for magnetism)
3. $\oint \mathbf{E}\cdot d\mathbf{l} = \frac{-d\Phi_B}{dt}$ (Faraday's Law)
4. $\oint \mathbf{B}\cdot d\mathbf{l} = \mu_0 i_c + \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt}$ (Ampere – Maxwell Law)

Transverse nature of e. m . waves

Consider an electromagnetic wave travelling in positive X direction. The electric and magnetic fields associated with a frequency same as that of the wave. The electric and magnetic fields are perpendicular to each other and to the direction of propagation of the wave. Hence they can be presented as:

$E_y = \{E_0 \sin [kx - \omega t]\}\, j$ and $E_x = E_z = 0$

$B_z = \{B_0 \sin [kx - \omega t]\}\, k$ and $B_x = B_y = 0$ Where $\omega = 2\pi/\lambda$

This shows that electromagnetic wave is transverse in nature with the same phase for both electric and magnetic fields. i.e., the phase difference between electric and magnetic fields at any instant is 0.

Note: the velocity of e. m. waves is given by

the following equations (i) $c = v\lambda$ (ii) $c = E_0 / B_0$ (iii) $c = 1/\sqrt{\mu_0\varepsilon_0}$

Energy density: It is the energy possessed per unit volume in a given region during the propagation of an e.m. wave. It is due to electric and magnetic fields.

(i)Due to electric field: $u_E = \frac{1}{2}\varepsilon_0 E_{rms}^2$ or $u_E = \frac{1}{2}\varepsilon_0 (E_0/\sqrt{2})^2$ i.e., $u_E = \frac{1}{4}\varepsilon_0 E_0^2$

(ii) Due to magnetic field :$u_B = \frac{1}{2}\mu_0 B_{rms}^2$ or $u_B = \frac{1}{2}\mu_0 (B_0/\sqrt{2})^2$ i.e., $u_B = \frac{1}{4}\mu_0 B_0^2$

Qn. Show that the energy density due to magnetic and electric fields are equal.

$u_E = \frac{1}{4}\varepsilon_0 E_0^2 = \frac{1}{4}\varepsilon_0 (c B_0)^2$ [$c = E_0/B_0$ and $c = 1/\sqrt{\mu_0\varepsilon_0}$]

$= \frac{1}{4}\varepsilon_0 c^2 B_0^2 = \frac{1}{4}\varepsilon_0 (1/\mu_0\varepsilon_0) B_0^2$

$= \frac{1}{4}\mu_0 B_0^2$

i.e., $u_E = u_B$

Note: Thus the total energy density $= u_E + u_B = \frac{1}{4}\varepsilon_0 E_0^2 + \frac{1}{4}\mu_0 B_0^2$

$= \frac{1}{2}\varepsilon_0 E_0^2$ or $\frac{1}{2}\mu_0 B_0^2$

Radiation Pressure

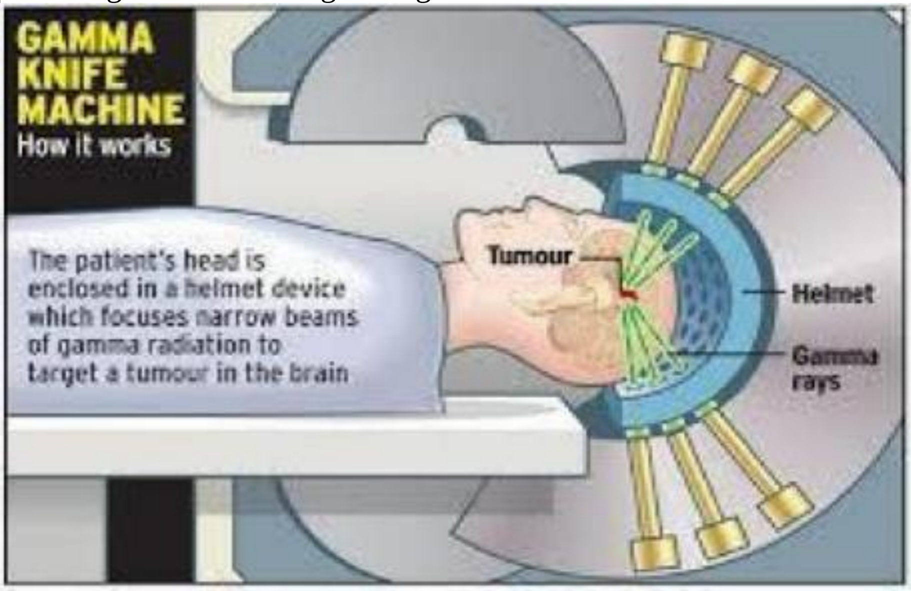
An electromagnetic wave (like other wave) carries energy and momentum. Since it carries momentum, an electromagnetic wave also exerts pressure, called radiation pressure. If the total energy transferred to a surface in time t can be shown that the magnitude of the total momentum delivered to this surface (for complete absorption) is $p = u/c$

S. No.	Question Details				Marks
	MULTIPLE CHOICE QUESTIONS				
1.	What is wavelength of signal weather frequency of 300 megahertz?				1
	A	2m	B	20m	
	C	10m	D	1m	
2.	If λx , λm , λv represents wavelength of X-Rays, microwaves & visible rays then				1
	A	$\lambda m > \lambda x > \lambda v$	B	$\lambda m > \lambda v > \lambda x$	
	C	$\lambda v > \lambda x > \lambda m$	D	$\lambda v > \lambda m > \lambda x$	
3.	EM waves can be produced by a charge:				1
	A	An accelerated charged particle	B	at rest.	
	C	A charged particle moving with constant speed	D	either at rest or moving with constant velocity.	
4.	In EM spectrum minimum wavelength is of:				1
	A	gamma rays	B	radio waves	
	C	visible rays	D	microwave	
5.	Which of the following is transported by EM waves:				1
	A	charge & momentum	B	frequency & wavelength	
	C	energy & momentum	D	wavelength & energy	
6.	A plane electromagnetic wave travels along y-axis in vacuum, its electric and magnetic field vectors are along				1
	A	z-axis and x-axis.	B	z-axis and y-axis.	
	C	y-axis and x-axis.	D	x-axis and z-axis.	
7.	Name the em wave used for detecting fracture in bones				1
	A	X- rays	B	UV rays	
	C	Infra-red rays	D	Visible rays	
8.	Name the em wave used for water purification				1
	A	X- rays	B	UV rays	
	C	Infra-red rays	D	Visible rays	

9.	The speed of propagation of a wave is given by	1
	A k/λ. B ω/k. C k/ω. D ω/c.	
10.	For all the em waves, what is the same?	1
	A frequency B speed C Wave number D wavelength	
	FILL IN THE BLANKS	
11.	Shorter the wavelength of an electromagnetic waves ,……... energy it carries	1
12.	Electromagnetic waves are…………….waves.	
13.	In EM waves transport both….…and……. takes place.	1
14.	To treat cancer and tumor in radiography……... rays are used.	1
15.	For an EM wave propagating along x –axis E_0=30V/m, the maximum value of magnetic field is….	1
16.	The conduction current is same as ----------------------------------- whether the source is A.C only.	1
17.	An oscillating charge particle radiates --------------------------------------.	1
18.	During the propagation of an EM wave in a medium electrical energy density is ------------------magnetic energy density	1
19.	Human body radiate………... of EM spectrum	1
20.	The correct equation of maxwell ampere circuital law is -----------------	
	ASSERTION AND REASON	
	Two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below. **a) Both A and R are true and R is the correct explanation of A** **b) Both A and R are true and R is NOT the correct explanation of A 1** **c) A is true but R is false** **d) A is false and R is also false**	
1.	Assertion: Electromagnetic waves exert radiation pressure. Reason: Electromagnetic waves carry energy.	
2.	Assertion: The electromagnetic wave is transverse in nature. Reason: Electromagnetic wave propagates parallel to the direction of electric and magnetic fields.	
3.	Assertion: The velocity of electromagnetic waves depends on electric and magnetic properties of the medium. Reason: Velocity of electromagnetic waves in free space is constant.	

4.	Assertion: Infrared radiation plays an important role in maintaining the average temperature of earth. Reason: Infrared radiations are sometimes referred to as heat waves	
5.	Assertion: The basic difference between various types of electromagnetic waves lies in their wavelength or frequencies. Reason: Electromagnetic waves travel through vacuum with the same speed.	
	1 MARKER QUESTIONS	
21.	Which part of electromagnetic spectrum has the largest penetrating power?	1
22.	Write the following radiation in the ascending order of their frequencies: X-rays, microwaves, ultraviolet rays and radio waves.	1
23.	On what factors does the velocity of light in vacuum depend?	1
24.	What is the phase relation between electric and magnetic oscillations in electromagnetic waves?	1
25.	The current in an a.c circuit containing a capacitor is 0.15A. What is the value of displacement current and where does it exist?	1
26.	Write the mathematical expression for displacement current.	1
27.	Name the electromagnetic waves used for studying crystal structure.	1
28.	Give the ratio of velocities of light rays of wavelength 4000 A^o and 8000 A^o in vacuum.	1
29.	An em wave exerts pressure on the surface on which it is incident. Justify.	1
30.	A variable frequency AC source is connected to a capacitor. Will the displacement current change if the frequency of the AC source is decreased?	1
	2 MARKER QUESTIONS	
31.	Find the wavelength of electromagnetic waves of frequency 5×10^{19} Hz in free space. Give its two applications.	2
32.	A plane electromagnetic wave travels, in vacuum, along the y-direction. Write the (a) ratio of the magnitude, and (b) the directions of its electric and magnetic field vectors.	2
33.	Which of the following if any, can act as a source of electromagnetic waves? (a) A charge moving with a constant velocity (b) A charge moving in a circular orbit (c) A charge at rest. Give reason.	2
34.	Name the waves that are often referred to as heat waves. Name the physical quantity that has a (a) lower (b) higher (c) same value for these waves, as compared to its value, for X-rays.	2
35.	A plane electromagnetic wave of frequency 25MHz travels in free space along the x-direction. At a particular point in space and time the electric vector is E=6.3 j V/m. Calculate magnetic field vector B at this point	2

36.	Why are microwaves better carriers of signals than radio waves?	2
	3 MARKER QUESTIONS	
37.	What is meant by the transverse nature of electromagnetic waves? Draw a diagram showing the propagation of an electromagnetic wave along the x-direction, indicating clearly the directions of the oscillating electric and magnetic fields associated with it .	3
38.	When can a charge act as a source of electromagnetic waves? How are the directions, of the electric and magnetic field vectors, in an electromagnetic wave, related to each other and to the direction of propagation of the wave?	3
39.	Identify the part of the electromagnetic spectrum which is (a) Suitable for radar system used in aircraft navigation. (b) Water Purification (c) Produced in nuclear reactions. (d) Produced by bombarding a metal target by high speed electrons. (e) produced by klystrons and magnetrons (f) used to study crystal structure.	3
40.	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 defection during the process of charging? If so, how would you explain this momentary deflection and the resulting continuity of current in the circuit? Wire the expression for the current inside the capacitor	3
41.	a) How are electromagnetic waves produced? What is the source of energy of these waves? b) Draw a schematic sketch of the electromagnetic waves propagating along the +x axis. Indicate the direction of the electric and magnetic fields.	3
42.	The oscillating electric field of an electromagnetic wave is given by $E_Y = 30\sin(2\times\ 10^{11}\ t + 300\pi x)\,Vm^{-1}$ a) Write down the expression for oscillating magnetic field. b) Sketch the corresponding *em* wave with its electric field and magnetic field.	3
43.	Suppose that the electric field amplitude of an em wave is E_0= 120N/C and that its frequency if 50.0MHz. a) Find the expression for magnetic field and electric field if the wave is propagating along y axis b) Sketch the corresponding em wave with its electric field and magnetic field.	3
44.	The magnetic field in a plane electromagnetic wave is given by $B_Y = 2x10^{-7}$ Sin $(0.5x10^3x + 1.5x10^{11}t)$ T a) What is the wavelength and frequency of the wave? b) Write an expression for the electric field.	3
45.	Define displacement current. What role does it play while charging a capacitor by dc source. Is the value of displacement current same as that of the conduction current ? Explain.	3
	CASE STUDY	
46.	In an electromagnetic wave both the electric and magnetic fields are perpendicular to the direction of propagation, that is why electromagnetic waves are transverse in nature. Electromagnetic waves carry energy as they travel through space and this energy is shared	4

	equally by the electric and magnetic fields. Energy density of an electromagnetic waves is the energy in unit volume of the space through which the wave travels. (i) Mention the direction of the electromagnetic waves propagated perpendicular to both $\vec{E}$**i** and $\vec{B}$**.j** (ii)Write the source of an electromagnetic wave. (iii)Which phenomenon provides the evidence that Electromagnetic waves are transverse in nature? (v) Give the relation of phase of the electric and magnetic fields of an electromagnetic waves are	
47.	**GAMMA RAYS IN TREATMENT OF CANCER** Gamma rays are used in radiotherapy to treat cancer. They are used to spot tumours. They kill the living cells and damage malignant tumour.  1.What is the source of gamma rays? 2. Name two EM waves which have higher wavelength than gamma rays. 3. Which EM Wave other than gamma is used in the treatment of cancer ? 5. Which EM Waves has least penetrating Power and write its wavelength range?	4

ANSWER KEY - MCQ

1	2	3	4	5
D	B	A	A	C

6	7	8	9	10
A	A	B	B	A

ANSWER KEY -FILL IN THE BLANKS

11	12	13	14	15
Higher	Non mechanical	Energy, momentum	Gamma	10^{-7}T
16	**17**	**18**	**19**	**20**
Displacement current	E. M. Waves	Equal	Infrared wave	$\oint \vec{B} \cdot \overline{dl} = \mu_0 \left(i_c + \varepsilon_0 \frac{d\phi_E}{dt} \right)$

ANSWER KEY – ASSERTION AND REASON

1	2	3	4	5
a	c	b	b	a