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CBSE

CLASS 12TH

THE CENTRAL BOARD OF SECONDARY EDUCATION

PART – IX

PHYSICS - II

SIERRA INNOVATIONS

Physics - 2

Chapter 8
Electromagnetic Waves

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Electromagnetic Waves

The EM waves are produced by the accelerated charge. The electric and magnetic fields produced by the accelerated charge change with time. Hence, it radiates electromagnetic waves, for example, the electron jumping form outer to inner orbit of the electron radiates EM waves. Similarly, the electrical oscillations in the LC circuit can produce EM waves. Even electric sparking generates EM waves.

Characteristics of EM waves are as follows,

i. EM waves are propagated as electric and magnetic field oscillating in mutually perpendicular directions.
ii. EM waves travel in vacuum along straight line with a velocity 2.9979 x 10^8 ms^{-1} which is often assumed as 3.8 x 10^8 ms^{-1}.
iii. EM waves are not affected by electric and magnetic fields.
iv. The electric and magnetic field components are related to each other as E = Bc, where c = 3.8 x 10^8 ms^{-1}.
v. In principle, the electromagnetic wave can be of length(ƛ) from 0 to ∞. Also corresponding frequencies (f) can be from ∞ to 0. The ƛ and f are related as: c = f ƛ.

Displacement Current

The current which comes into play m the region in which the electric field and the electric flux is changing with time. It is given by

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

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.

Note: The displacement current produces in space due to change of electric flux linked with the surface. This reveals that, varying electric field is the source of magnetic field.

Maxwell's Equations of Electromagnetic

Waves Maxwell's equations are the basic laws of electricity and magnetism. These equations give complete description of ail electromagnetic interactions.
There are four Maxwell's equations which are explained below:

i. Gauss' law in electrostatics,

$$\oint E.dS = \frac{q}{\varepsilon_0}$$

ii. Gauss's law in magnetism,

$$\oint B.dS = 0$$

iii. Faraday's law of electromagnetic induction,

$$\oint E.dl = -\frac{d\phi_B}{dt}$$

iv. Modified Ampere's circuital law,

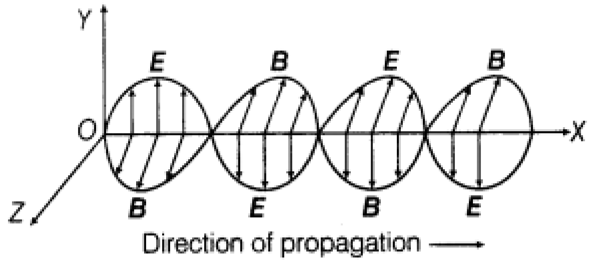
$$\oint B.dl = \mu_0(I_c + I_D)$$

Where, I_c is conduction current and I_D is displacement current and given by,

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

Important considerations of Electromagnetic waves

These are transverse in nature, i.e. electric and magnetic fields are perpendicular to each other and to the direction of wave propagation. Electromagnetic waves are not deflected by electric and magnetic fields.



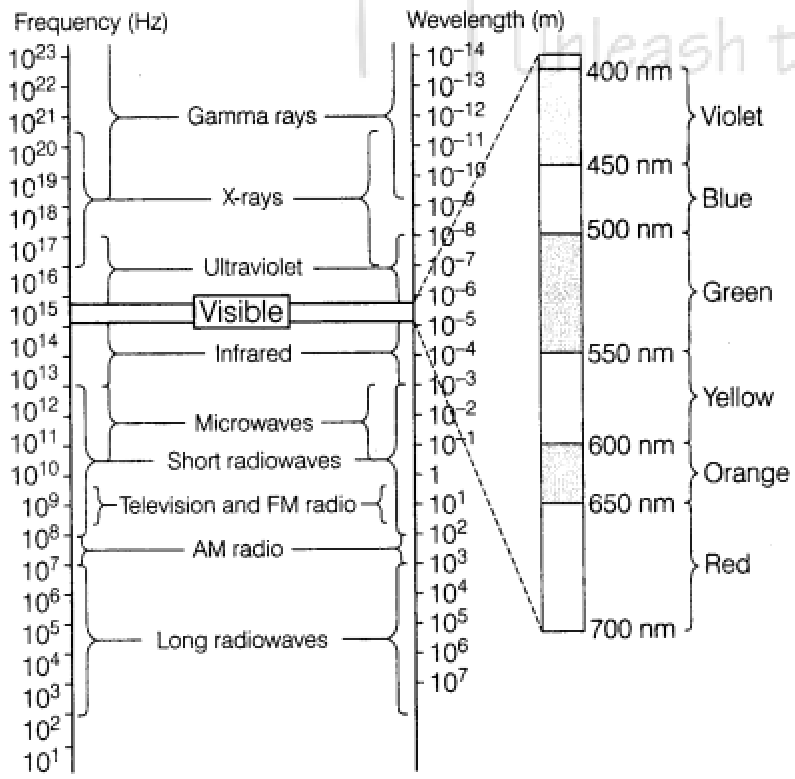
- E (electric field) and B (magnetic field) in electromagnetic waves are in same phase.
- Speed of electromagnetic wave

$$c = \frac{E_0}{B_0} = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3 \times 10^8 m/s$$

- The energy in electromagnetic wave is divided on average equally between electric and magnetic fields.
- Energy associated with an electromagnetic wave is $U = \frac{1}{2} \epsilon_0 \, E^2 + \frac{B^2}{2\mu_0}$
- Linear momentum delivered to the surface, p= U/c
  where, U = total energy transmitted by electromagnetic waves and c = speed of electromagnetic wave.

Electromagnetic Spectrum

The systematic sequential distribution of electromagnetic waves in ascending or descending order of frequency or wavelength is known as electromagnetic spectrum. The range varies from 10^{-12} m, to 10^{4} m, i.e. from γ-rays to radio waves.



Elementary facts about the uses of electromagnetic waves

Radio waves

(i) In radio and TV communication.
(ii) In astronomical field.

Microwaves

(i) In RADAR communication.
(ii) In analysis of molecular and atomic structure.
(iii) For cooking purpose.

Infrared waves

(i) In knowing molecular structure. (ii) In remote control of TV VCR, etc.

Ultraviolet rays

(i) Used in burglar alarm. (ii) To kill germs in minerals.

X-rays

(i) In medical diagnosis as they pass through the muscles not through the bones.
(ii) In detecting faults, cracks, etc., in metal products,

γ-rays

(i) As food preservation. (ii) In radiotherapy.

Note: The optical effect is produced by electric field vector of the electromagnetic waves.

Different types of EM

Type	Wave length	Frequency	Production

	range	range (Hz)	
Radio wave	>0.1m	$3 \times 10^{3}\ to\ 3 \times 10^{8}$	Rapid acceleration and deceleration of electron in ariels
Microwave	0.1m to 1 mm	$3 \times 10^{8}\ to\ 3 \times 10^{11}$	Kylestron valve or magnetron
Infrared wave	1mm to 700nm	$3 \times 10^{11}\ to\ 4 \times 10^{14}$	Vibration of atom and molecules
Light	700nm to 400nm	$4 \times 10^{14}\ to\ 8 \times 10^{14}$	Electrons when move from one energy level to a lower energy level
Ultraviolet rays	400nm to 1nm	$8 \times 10^{14}\ to\ 8 \times 10^{16}$	Inner shell electrons in atom moving from one energy level to a lower energy level
X – rays	1nm to 10^{-3}nm	$1 \times 10^{16}\ to\ 3 \times 10^{21}$	x-ray tubes or inner shell electrons
γ - rays	<10^{-3}nm	$5 \times 10^{18}\ to\ 5 \times 10^{22}$	Radioactive decay of nucleus

Points to remember

• In an electric circuit having a charged capacitor, the current flowing through the connecting wires is called conduction current; while that flowing through the gap between the plates of capacitor is called displacement current.

• The displacement current owes its origin to the varying electric field between the two plates of a charged capacitor.

• Maxwell's equations are mathematical formulation of Gauss' law in electrostatics, Gauss'law in magnetism, Faraday's law of electromagnetic induction and Ampere's circuital law.

• Electromagnetic Waves are transverse in nature.

• The frequency of electromagnetic waves is its inherent characteristic. When an electromagnetic wave travels from one medium to another, it's wavelength changes but frequency remains unchanged.

• All the types of electromagnetic waves travel with the same speed in free space.

• Short wavelength infra-red radiation is often called an infra-red light, though it cannot excite vision.

Chapter-8

1 Mark Questions

Q.1) Name the part of the electromagnetic spectrum of wavelength 10^{-2} m and mention its one application.

Sol:
Name of the part: Microwave
Applications :

1. It is used in radar communication.
2. It is used in microwave ovens.
3. It is also used in analysis of fine details of molecular and atomic structure.

Q.2) Name the part of electromagnetic spectrum which is suitable for

1. **radar systems used in aircraft navigation**
2. **Treatment of cancer tumours.**

Sol:

1. Micro-waves
2. Gamma-rays.

Q.3) which part of electromagnetic spectrum is used in radar systems?

Sol: Microwave region of electromagnetic spectrum is used in radar systems.

Q.4) Name the part of electromagnetic spectrum whose wavelength lies in the range of 10^{-10} m. Give its one use.

Sol: Name: X-rays
Use: In medical diagnosis to look for broken bones; treatment study of crystal structure.

Q.5) In which directions do the electric and magnetic field vectors oscillate in an electromagnetic wave propagating along the x-axis?

Sol:
Electric field ($\vec{E}$) oscillates along y-axis and magnetic field ($\vec{B}$) oscillates along z-axis; in an electromagnetic wave propagating along the x-axis.

Q.6) how is the speed of em-waves in vacuum determined by the electric and magnetic fields?

Sol: Speed of EM - waves in vacuum is determined by the ratio of the peak values of electric and magnetic field vectors.

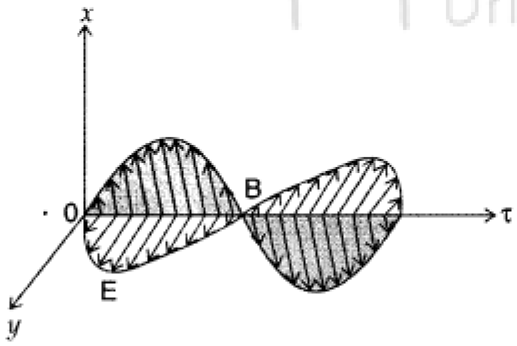
2 Marks Questions

Q.1) The oscillating electric field of an electromagnetic wave is given by:
$E = 30 \sin [2 \times 10^{11} t + 300 \pi x]$ Vm^{-1}
(a) Obtain the value of the wavelength of the electromagnetic wave.
(b) Write down the expression for the oscillating magnetic field.

Sol:
(a) We compare the given expression with

Q.2) how does a charge q oscillating at certain frequency produce electromagnetic waves? Sketch a schematic diagram depicting electric and magnetic fields for an electromagnetic wave propagating along the Z-direction.
Sol:
As the charge q moves accelerating, the electric field and magnetic field produced will change the space and time E and B varying with time produced the other field B and E respectively and sustain the E.M. pattern.

This is from the interpretation of Maxwell supported by



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?

Sol: A dc battery connected to an ideal capacitor ‘ provides only a momentarily charge, whereas an ac battery allows a continuous flow of current
As charge on capacitor plates changes, electric field associated with that also changes and hence giving rise to a displacement current according to

Q.4) dentifiy the electromagnetic waves whose wavelengths lie in the range
(a) 10^{-11} m < λ < 10^{-8} m
(b) 10^{-4} m < λ < 10^{-6} m Write one use of each.

Sol: (a) Uses of X-Rays and Gamma rays:
X-rays are used as a diagnostic tool in medicine and as a treatment for certain forms of cancer. Gamma rays are used in medicine to destroy cancer cells.

(b) Uses of Infrared, visible and microwaves:

- Infrared waves are widely used in remote switches of household electronic systems such as remotes for TVs, video recorders etc.
- Visible rays provide us information about the world.
- Microwaves are used in the radar systems in aircraft navigation.

Q.5) for a plane electromagnetic wave, propagating along the Z-axis, write the two (possible) pairs of expression for its oscillating electric and magnetic fields. How is the peak values of these (oscillating) fields related to each other?
Sol:
For the e.m. wave, propagating along the z-axis, we have
The two possible forms for electric and magnetic fields are :
The peak values of these two fields are related by

Q.6) Name the types of e.m. radiations which

1. **are used in destroying cancer cells,**
2. **cause tanning of the skin and**
3. **Maintain the earth's warmth.**

Write briefly a method of producing any one of these waves.

Sol:

1. γ-rays
2. Ultraviolet rays
3. Infrared rays

Mode of production

1. γ-rays are produced by radioactive decay of nucleus.
2. Ultraviolet rays are produced when inner shell electrons in atoms move from one energy level to another energy level.
3. Infrared rays are produced due to vibration of atoms and molecules.

3 Marks Questions

Q.1) Identify the following electromagnetic radiations as per the wavelengths given below. Write one application of each.
(a) 10^{-3} nm
(b) 10^{-3} m
(c) 1 nm
Sol:
(a) 10^{-3} nm : γ-rays
Application :

1. γ-rays are used in the treatment of cancer and tumour.
2. γ-rays are used in radiation therapy. (any one)

(b) 10^{-3} m: Microwave
Application: Microwaves are used in Radar systems for aircraft navigation.

(c) 1 nm: X-rays

Application:

1. Infra-red waves are used for taking photographs during the conditions of fog, smoke etc.
2. These are also used as a diagnostic tool for the detection of fractures, (any one)

Q.2) (a) How does an oscillating charge produce electromagnetic wave? Explain.
(b) Draw a sketch showing the propagation of a plane em wave along the Z-direction, clearly depicting the directions of oscillating electric and magnetic field vectors.

Sol:
(a) Consider a charge oscillating with same frequency. This produces an oscillating electric field in space, which produces an oscillating magnetic field which in turn is a source of oscillating electric field and so on. The oscillating electric and magnetic fields thus regenerate each other, as the waves propagate through the space. The frequency of the electromagnetic wave naturally equals the frequency of the oscillation of the charge.

(b) Sketch of a plane electromagnetic wave propagating along the z-direction with oscillating electric field E along the x-direction and the oscillating magnetic field B along the y-direction.

Q.3) (a) When the oscillating electric and magnetic fields are along the x- and indirection respectively

1. **Point out the direction of propagation . of electromagnetic wave.**
2. **Express the velocity of propagation in terms of the amplitudes of the oscillating electric and magnetic fields.**

(b) How do you show that the em wave carries energy and momentum?

Sol:
(a)

1. Along z-direction.
2. Velocity of propagation will be, C=E0B0

(b) Photoelectric effect shows the particle nature of electromagnetic waves. As such the photons carry energy and momentum. The energy is given by

Q.4) Name the parts of the electromagnetic spectrum which is
(a) suitable for radar systems used in aircraft navigation.
(b) Used to treat muscular strain.
(c) Used as a diagnostic tool in medicine.
Write in brief, how these waves can be produced.
Sol:
(a) Microwaves
Production : Klystron/magnetron

(b) Infrared Radiations
Production; Hot bodies/vibrations of atoms and molecules.

(c)X-Rays
Production: Bombarding high energy electrons on a metal target.

5 Marks Questions

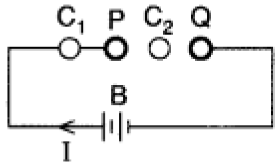
Q.1) (i) Identify the part of the electromagnetic spectrum which is :
(a) suitable for radar system used in aircraft navigation,
(b) produced by bombarding a metal target by high speed electrons.
(ii) Why does a galvanometer show a momentary deflection at the time of charging or discharging a capacitor? Write the necessary expression to explain this observation.

Sol:
(i)
(a) Microwaves
(b) X-rays

(ii) The total current
(i) is the sum of conduction current
(i_c) and displacement current (i_d), so we have
This means that outside the capacitor plates in connecting wires, we have only conduction current i_c = i and no displacement current (i_d = 0). On the other hand, inside the capacitor, there is no conduction current (i_c = 0) and there is only displacement current hence i = i_d.
It is why there is momentary deflection in the galvanometer at the time of charging or discharging a capacitor.

Q.2) Write Maxwell's generalization of Ampere's Circuital Law. Show that in the process of charging a capacitor, the current produced within the plates of the capacitor is where φ E is electric flux produced during charging of the capacitor plates.

Sol: Maxwell's displacement current: According to Ampere's circuital law, the magnetic field B is related to steady current I as



Maxwell showed that this relation is logically in-consistent. He accounted this inconsistency as follows:
Ampere's circuital law for loop C_1 gives
which is logically inconsistent. So, Maxwell gave idea of displacement current.