

CHAPTER 08

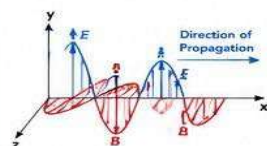
ELECTROMAGNETIC WAVES

CBSE CLASS XII PHYSICS

Electromagnetic waves are transverse waves which do not require a material medium for their propagation. They travel even in vacuum with speed c .

1 GENERATION OF ELECTROMAGNETIC WAVES

- When an accelerated charge oscillates, it produces time-varying electric and magnetic fields.
- According to Maxwell, a changing electric field produces a changing magnetic field and vice-versa.
- These mutually perpendicular fields propagate in space in the form of electromagnetic waves.



Key Points

- $E \perp B \perp$ direction of propagation
- E and B are in phase
- Electric and magnetic fields perform SHM in mutually perpendicular planes

2 PROPERTIES OF ELECTROMAGNETIC WAVES

- Do not require material medium.
- Travel with speed c in vacuum.
- E and B fields are perpendicular to each other and to the direction of propagation.
- All electromagnetic waves are transverse.
- Obey laws of reflection, refraction, interference, diffraction and polarization.
- In vacuum, all EM waves travel with same speed c .

Speed in Vacuum

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 3.0 \times 10^8 \text{ m s}^{-1}$$

Where,

$$\mu_0 = 4\pi \times 10^{-7} \text{ T m A}^{-1} \text{ (permeability of free space)}$$

$$\epsilon_0 = 8.854 \times 10^{-12} \text{ F m}^{-1} \text{ (permittivity of free space)}$$

3 MATHEMATICAL DESCRIPTION

Sinusoidal EM Wave

Electric Field:

$$E = E_0 \sin(kx - \omega t)$$

Magnetic Field:

$$B = B_0 \sin(kx - \omega t)$$

Where,

E_0 = amplitude of electric field (V m^{-1})

B_0 = amplitude of magnetic field (T)

k = wave number = $\frac{2\pi}{\lambda}$ (rad m^{-1})

ω = angular frequency = $2\pi f$ (rad s^{-1})

λ = wavelength (m)

f = frequency (Hz)

t = time (s)

x = distance in direction of propagation (m)

Relation between E_0 and B_0

$$\frac{E_0}{B_0} = c \quad \text{or} \quad E_0 = cB_0$$

Wave Relations

$$c = \lambda f$$

$$\omega = 2\pi f = \frac{2\pi c}{\lambda}$$

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

4 ENERGY, MOMENTUM AND PRESSURE

Energy Density

Electric Field:

$$u_E = \frac{1}{2} \epsilon_0 E^2$$

Magnetic Field:

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

Total Energy Density (u):

$$u = u_E + u_B = \frac{1}{2} \epsilon_0 E^2 + \frac{1}{2} \frac{B^2}{\mu_0}$$

In EM wave, average u_E = average u_B

$$\Rightarrow u_{avg} = \epsilon_0 E_{rms}^2$$

Intensity (I)

Average energy crossing unit area per unit time.

$$I = \langle S \rangle = c u_{avg} = \frac{1}{2} c \epsilon_0 E_0^2$$

$$\text{Also, } I = \frac{c}{2\mu_0} B_0^2$$

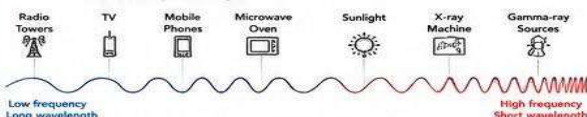
Radiation Pressure (P)

$$P = \frac{I}{c} \quad (\text{perfect absorber})$$

$$P = \frac{2I}{c} \quad (\text{perfect reflector})$$

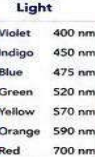
5 ELECTROMAGNETIC SPECTRUM

The EM spectrum arranged according to increasing frequency (f) or decreasing wavelength (λ).



Region	Wavelength (m)	Frequency (Hz)	Uses / Sources
Radio Waves	> 1	$< 3 \times 10^8$	Radio, TV, communication
Microwaves	$10^{-3} - 1$	$3 \times 10^8 - 3 \times 10^{11}$	Radar, ovens, Wi-Fi
Infrared (IR)	$10^{-6} - 10^{-3}$	$3 \times 10^{11} - 3 \times 10^{14}$	Heating, remote controls
Visible Light	$400 - 700 \text{ nm}$	$4.3 \times 10^{14} - 7.5 \times 10^{14}$	Vision, photography
Ultraviolet (UV)	$10^{-8} - 400 \text{ nm}$	$7.5 \times 10^{14} - 3 \times 10^{16}$	Sterilization, fluorescent lamps
X-rays	$10^{-11} - 10^{-8}$	$3 \times 10^{16} - 3 \times 10^{19}$	Medical imaging
Gamma rays	$< 10^{-11}$	$> 3 \times 10^{19}$	Cancer treatment, nuclear

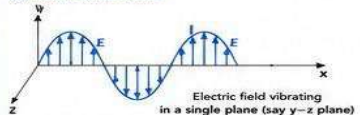
Visible Light



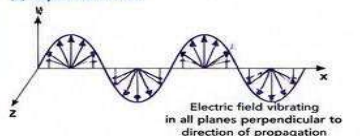
6 POLARIZATION OF ELECTROMAGNETIC WAVES

Polarization is the phenomenon of restricting the direction of vibration of the electric field vector.

(a) Plane Polarized Wave



(b) Unpolarized Wave



PYQ

Why can electromagnetic waves be polarized while sound waves cannot be?



MEMORY TRICK

Electromagnetic waves are SELF-sustaining waves of oscillating E and B fields!

QUICK REVISION

- EM waves are transverse.
- $E \perp B \perp$ direction of propagation.
- Do not need a medium.
- Speed in vacuum: $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$
- All EM waves travel with same speed in vacuum.
- Energy is shared equally between E and B fields.
- EM waves show reflection, refraction, interference, diffraction, polarization.

FORMULA SUMMARY

Speed in vacuum	$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$
Wave equation	$c = \lambda f$
Angular frequency	$\omega = 2\pi f$
Wave number	$k = \frac{2\pi}{\lambda}$
Amplitude relation	$E_0 = cB_0$
Energy density	$u = \frac{1}{2} \epsilon_0 E^2 + \frac{1}{2} \frac{B^2}{\mu_0}$
Intensity	$I = \frac{1}{2} c \epsilon_0 E_0^2 = \frac{c}{2\mu_0} B_0^2$
Radiation pressure	$P = \frac{I}{c}$ (absorber) $P = \frac{2I}{c}$ (reflector)

INTERFERENCE OF EM WAVES

Superposition of two coherent EM waves produces interference.

Conditions

- Coherent sources
- Same frequency
- Constant phase difference
- Same state of polarization

Result

- Constructive interference (bright): $\Delta = n\lambda$
- Destructive interference (dark): $\Delta = (2n+1) \frac{\lambda}{2}$

where, Δ = path difference

COMMON MISTAKES

- Thinking EM waves need medium.
- Forgetting $E \perp B \perp$ direction.
- Confusing f and ω .
- Using v instead of c in vacuum.
- Forgetting $E_0 = cB_0$.
- Not converting units in numerical problems.

INTERFERENCE & DIFFRACTION

	Interference	Diffraction
Cause	Superposition of waves from two coherent sources	Bending/spreading of waves around edges or through aperture
Source(s)	Two coherent sources	Single source
Fringe Pattern	Bright & dark fringes of equal width (ideal)	Central maximum is brightest & widest; side maxima weaker
Dependence	Depends on d, D, λ	Depends on a, λ
Condition	Requires coherence	No coherence required

PYQ TIPS

- Derivations are important: Generation of EM waves, expression for speed of light, energy density.
- Learn diagrams neatly.
- Know the EM spectrum order.
- Practice numericals regularly.
- Focus on NCERT end-of-chapter questions and previous 10 years' board questions.

BOARD EXAM TIPS

- Write all formulas with symbols.
- Draw labelled diagrams first.
- Use correct units (SI).
- Show all steps in derivations.
- Attempt NCERT in-text & exemplar questions.
- Revise PYQs before exam.

SYMBOLS & UNITS

Symbol	Quantity	SI Unit
E	Electric field	V m^{-1}
B	Magnetic field	tesla (T)
c	Speed of light in vacuum	m s^{-1}
λ	Wavelength	metre (m)
f	Frequency	hertz (Hz)
ω	Angular frequency	rad s^{-1}
μ_0	Permeability of free space	T m A^{-1}
ϵ_0	Permittivity of free space	F m^{-1}

"Electromagnetic waves are nature's universal messengers."

MULTIPLE CHOICE QUESTIONS

1. Which of the following has the minimum wavelength?
 (a) X-rays (b) Ultraviolet rays (c) Gamma rays (d) Cosmic rays
2. Which of the following can produce a propagating electromagnetic wave?
 (a) A stationary charge (b) A chargeless particle
 (c) An accelerating charge (d) A charge moving at constant velocity
3. Which one of the following correctly represents the change in wave characteristics (all in vacuum) from microwaves to X rays in electromagnetic spectrum?

Speed	Wavelength	Frequency
a) Remains same	Decreases	Remains same
b) Remains same	Decreases	Increases
c) Increases	Increases	Decreases
d) Remains same	Decreases	Remains same
4. X rays are more harmful to human beings than ultraviolet radiations because X-rays:
 a) Have frequency lower than that of ultraviolet radiations
 b) Have wavelength smaller than that of ultraviolet radiations
 c) Move faster than ultraviolet radiations in air
 d) Are mechanical waves but ultraviolet radiations are electromagnetic waves
5. Displacement current exists only when
 a) electric field is changing b) magnetic field is changing
 c) electric field is constant d) magnetic field is constant
6. The momentum (in kg m/s) of a photon of wavelength 500nm is:
 a) 6.63×10^{-25} b) 1.326×10^{-27} c) 2.652×10^{-26} d) 3.978×10^{-24}
7. The phase difference between the oscillations of electric and magnetic field in an electromagnetic wave is:
 a) π b) $\pi/2$ c) zero d) $3\pi/2$
8. A plane electromagnetic wave propagating along x direction can have the following pairs of E and B :
 a) E_x, B_y b) E_x, B_x c) E_y, B_x d) E_z, B_y
9. In the process of charging of a capacitor, the current produced between the plates of the capacitor is
 a) $\mu_0 \frac{d\phi_E}{dt}$ b) $\frac{1}{\mu_0} \frac{d\phi_E}{dt}$ c) $\epsilon_0 \frac{d\phi_E}{dt}$ d) $\frac{1}{\epsilon_0} \frac{d\phi_E}{dt}$
10. $\vec{E}$ and $\vec{B}$ represent the electric and the magnetic fields of an electromagnetic wave respectively. The direction of propagation of the wave is along:
 a) $\vec{B}$ b) $\vec{E}$ c) $\vec{E} \times \vec{B}$ d) $\vec{B} \times \vec{E}$

Answers

- 1(c) Gamma rays B X-rays , Micro and UV as wavelength decreases in this order
- 2(c) An accelerating charge
- 3(b) wavelength of X is smaller than UV
- 4(a) displacement current is $\epsilon_0 \left(\frac{d\phi_E}{dt} \right)$ so it exists only if electric field is changing
- 5(c) During welding, a high-intensity electric arc is generated, which emits a large amount of

ultraviolet rays

6 c

7 c

8 d

9 c

10 c

ASSERTION AND REASON QUESTIONS

For each question, select the correct option:

- (a) Both Assertion and Reason are true, and Reason is the correct explanation of Assertion.
- (b) Both Assertion and Reason are true, but Reason is not the correct explanation of Assertion.
- (c) Assertion is true, but Reason is false.
- (d) Assertion is false, but Reason is true.

Q1.Assertion (A): Electromagnetic waves do not require a material medium for their propagation.

Reason (R): Electromagnetic waves consist of oscillating electric and magnetic fields, which are self-sustaining in vacuum.

Q2.Assertion (A): In an electromagnetic wave, the electric and magnetic fields are always perpendicular to each other.

Reason (R): The directions of electric and magnetic fields in an EM wave are independent of the direction of wave propagation.

Q3.Assertion (A): The speed of electromagnetic waves in vacuum is equal to $1/\sqrt{\mu_0\epsilon_0}$

Reason (R): The values of μ_0 and ϵ_0 determine the properties of vacuum with respect to magnetic and electric fields, respectively

Q4.Assertion (A): X-rays can be used to detect fractures in bones.

Reason (R): X-rays have controlled penetrating power and are absorbed differently by different tissues.

Q5.Assertion (A): Ultraviolet rays are more energetic than infrared rays.

Reason (R): The frequency of ultraviolet rays is greater than that of infrared rays.

Q6.Assertion (A): Gamma rays have the longest wavelength in the electromagnetic spectrum.

Reason (R): Gamma rays have the lowest frequency among all EM waves.

Q7.Assertion (A): Microwaves are suitable for radar systems used in aircraft navigation.

Reason (R): Microwaves can penetrate through the ionosphere and reach long distances without significant attenuation.

Q8.Assertion (A): Electromagnetic waves carry both energy and momentum.

Reason (R): The energy and momentum in EM waves are carried by the magnetic field only.

Q9.Assertion (A): Infrared radiation is used in night vision devices.

Reason (R): Infrared radiation is emitted by hot bodies and can be detected even in the absence of visible light.

Q10.Assertion (A): The electric field vector in an EM wave oscillates in the direction of propagation.

Reason (R): Electromagnetic waves are longitudinal in nature.

ANSWERS

- 1.(a) EM waves are self-propagating due to mutual induction of E and B fields and do not need a medium.
2. (c) The fields are perpendicular to each other and to the direction of wave propagation they are not independent.
3. (a) Speed of EM wave in vacuum is derived using these constants.

4. (a) Bones absorb more X-rays than soft tissue, producing contrast.
5. (a) Energy $E = h\nu$; higher frequency = higher energy.
6. (d) Gamma rays have the shortest wavelength and highest frequency.
7. (a) Microwaves are used in radar as they can travel in the atmosphere and reflect from objects.
- 8.(c) Energy is shared by both electric and magnetic fields, not just magnetic.
9. (a) IR is emitted due to heat and used for thermal imaging.
10. (d) EM waves are transverse, not longitudinal; E field is perpendicular to propagation.

EXERCISE QUESTIONS

Q1 Assertion: The center of sensitivity of our eyes coincides with the centre of the wavelength distribution of the sun.

Reason: Humans have evolved with visions most sensitive to the strongest wavelengths received from the sun.

Q2 Assertion: When Infrared waves are incident on a surface vibrate not only the electrons, but the entire atom or molecules of a substance.

Reason: Due to vibration internal energy increases and consequently temperature decreases.

Q3 Assertion: Displacement current has the same physical effect as the conduction current.

Reason: During charging of a capacitor both conduction and displacement current are present in different regions of space.

Q4 Assertion: the speed of electromagnetic waves is less in vacuum and it increases as move to a medium.

Reason: The relative permittivity and permeability of a medium is less than that of vacuum.

Q5 Assertion: Ultraviolet radiations are used in LASIK eye surgery.

Reason: Ultraviolet radiations can be focused into very narrow beams of high precision applications.

Answers

1. A 2.C 3. B 4. D 5. A

VERY SHORT ANSWER TYPE QUESTIONS (2 MARKS)

Q1 You are given a $2\mu\text{F}$ parallel plate capacitor. How would you establish an instantaneous displacement current of 1mA in the space between its plates?

Q2 (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?

Q3 (i) Which part of the electromagnetic spectrum is used in operating a RADAR?

(ii) Why microwaves are considered suitable for radar systems used in aircraft navigation?

Q4 (i) Do electromagnetic waves carry energy and momentum?

(ii) How is the speed of EM-waves in vacuum determined by the electric and magnetic fields?

Q5 The amplitude of the magnetic field of a harmonic electromagnetic wave in vacuum is $B_0 = 510\text{ nT}$. What is the amplitude of the electric field part of the wave?

Q6 An E.M. wave, Y_1 , has a wavelength of 1cm while another e.m. wave, Y_2 , has a frequency of 10^{15} Hz . Name these two types of waves and write one useful application for each.

Q7 How are electromagnetic waves produced? Write their two characteristics.

- Q8** A laser beam of wavelength 500nm and power 5nW strikes normally on a perfectly reflecting surface of area 1 mm^2 of a body. It rebounds back from the surface. Find the force exerted by the laser beam on the body.
- Q9** A laser beam of frequency $3.0 \times 10^{14} \text{ Hz}$ produces average power of 9mW find i) the energy of photon of the beam and ii) the number of photons emitted per second on an average by the source.
- Q10** Identify the electromagnetic wave whose wavelength range is from about
(a) 10^{-12} m to about 10^{-18} m (b) 10^{-3} m to about 10^{-1} m . Write one use of each.

ANSWERS

- 1: by giving a varying potential difference of 500 V/s
- 2: The thin ozone layer in the upper atmosphere (stratosphere) is crucial because it absorbs most of the harmful ultraviolet (UV) radiation from the Sun. Without it, UV rays would reach Earth's surface and cause severe health issues like skin cancer, cataracts, and damage to ecosystems.
3. Microwaves (typically in the range of 1 mm to 30 cm wavelength or 1 GHz to 30 GHz frequency) are used in RADAR systems.
- SUITABILITY: Short Wavelengths allow for high resolution and accurate detection of small and distant objects. Penetration Capability: They can travel long distances through the atmosphere with minimal attenuation due to weather (like fog, rain). Efficient Reflection: Microwaves are strongly reflected by metal surfaces (like aircraft or terrain), making them ideal for object detection and ranging.
- 4 Yes, electromagnetic (EM) waves carry both energy and momentum. The energy is transported by the oscillating electric and magnetic fields. They exert radiation pressure on surfaces, proving they carry momentum as well. Speed of wave $c = (v) = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 3 \times 10^8 \text{ m/s}$
- 5 $E_0 = 153 \text{ V/m}$
6. Y_1 has a wavelength of 1 cm, which lies in the microwave region.
 Y_2 has a frequency of 10^{15} Hz , which falls in the ultraviolet (UV) region.
- Y_1 : Microwave, Application: Used in microwave ovens for cooking food.
- Y_2 : Ultraviolet (UV) wave, Application: Used for sterilizing medical instruments.
7. Electromagnetic waves are produced by an accelerated or oscillating electric charge, which creates a time-varying electric field. This changing electric field, in turn, generates a time-varying magnetic field, and together they propagate as an electromagnetic wave.

Characteristics:

Transverse Nature: Electric and magnetic fields oscillate perpendicular to each other and to the direction of wave propagation.

Do Not Require a Medium: They can travel through a vacuum at the speed of light ($3 \times 10^8 \text{ m/s}$). Or any other characteristics...

8. $F = 2P/c$, This is because for a perfectly reflecting surface, the momentum transferred per second (i.e., force) is double compared to absorption.
 $F = 3.33 \times 10^{-17} \text{ N}$, This is the force exerted by the laser beam on the reflecting surface.
9. $E = h\nu$, $h = 6.626 \times 10^{-34} \text{ Js}$, So $E = 1.9878 \times 10^{-19} \text{ J}$
no of photons = Power/Energy per photon, $n = 9 \times 10^{-3} \text{ W} / 1.9878 \times 10^{-19} \text{ J} = 4.52 \times 10^{16} \text{ photons}$

10. (a) Wavelength range: 10^{-12} to 10^{-18} m, Electromagnetic Wave: Gamma rays, Used to kill cancer cells in radiation therapy. (b) Wavelength range: 10^{-3} to 10^{-1} m
Electromagnetic Wave: Microwaves, Used in microwave ovens to heat food.

SHORT ANSWER TYPE QUESTIONS (3 MARKS)

1. State any three characteristics of electromagnetic waves. Why are electromagnetic waves called transverse waves?
2. Draw the electromagnetic spectrum in increasing order of wavelength. Write one important application of (i) Infrared rays (ii) Ultraviolet rays (iii) Gamma rays.
3. The frequency of an electromagnetic wave is 8×10^{14} Hz. Calculate its wavelength. Name the part of the electromagnetic spectrum to which it belongs.
4. An electromagnetic wave travels in vacuum along the z-axis. The electric field oscillates along the x-axis. Write the direction of oscillation of magnetic field and explain how the direction of propagation is determined.
5. Why are microwaves preferred for satellite communication? Give three reasons.
6. (Competency Based) A TV remote stops working when a thick black sheet is placed between the remote and the television. Name the electromagnetic waves used in the remote and explain the reason behind this observation.
7. (Competency Based) During foggy conditions, visible light is not suitable for long-distance photography, but infrared cameras work effectively. Explain why.
8. (Competency Based) Doctors advise limited exposure to ultraviolet radiation, yet UV lamps are used in hospitals. Explain both statements with suitable reasons.
9. (Competency Based) A student observed that communication signals received from satellites are highly directional and carry large amounts of data. Which electromagnetic waves are used? Explain with reasons.
10. (Competency Based Numerical) The wavelength of a radio wave transmitted by a TV station is 6 m. Calculate its frequency. Why are such waves suitable for communication over large distances?

Answers

1. Characteristics: (i) Electromagnetic waves are transverse in nature. (ii) They can travel through vacuum. (iii) Electric and magnetic fields oscillate perpendicular to each other and to the direction of propagation. They are called transverse because the oscillations are perpendicular to the direction of motion.
2. Increasing order of wavelength: Gamma rays < X-rays < Ultraviolet < Visible < Infrared < Microwaves < Radio waves. Applications: Infrared rays – remote controls/thermal imaging; Ultraviolet rays – sterilization; Gamma rays – cancer treatment.
3. Given frequency, $\nu = 8 \times 10^{14}$ Hz. Using $c = \nu\lambda$, $\lambda = c/\nu = (3 \times 10^8)/(8 \times 10^{14}) = 3.75 \times 10^{-7}$ m. The wave belongs to the visible/near ultraviolet region.
4. Magnetic field oscillates along the y-axis. The direction of propagation is perpendicular to both electric and magnetic fields and is given by $\mathbf{E} \times \mathbf{B}$ (right-hand rule).
5. Microwaves are preferred because: (i) They can penetrate the atmosphere easily. (ii) They suffer less attenuation. (iii) Their short wavelength allows highly directional transmission and large bandwidth.

6. Infrared waves are used in TV remotes. The black sheet absorbs or blocks infrared radiation, preventing the signal from reaching the television sensor.
7. Infrared waves have longer wavelength and undergo less scattering in fog compared to visible light. Hence, infrared cameras work more effectively in foggy conditions.
8. Excessive ultraviolet exposure can damage skin and eyes and may cause cancer. However, UV lamps are used in hospitals because ultraviolet radiation kills bacteria and microorganisms.
9. Microwaves are used for satellite communication because they are highly directional, can penetrate the atmosphere effectively, and carry large amounts of information due to high frequency.
10. Given wavelength, $\lambda = 6 \text{ m}$. Using $v = c/\lambda = (3 \times 10^8)/6 = 5 \times 10^7 \text{ Hz}$. Radio waves are suitable for long-distance communication because they can diffract around obstacles and follow the curvature of the Earth.

Practice Questions

1. State the main differences between electromagnetic waves and mechanical waves. Give any three points.
2. A source emits electromagnetic waves of wavelength $3 \times 10^{-7} \text{ m}$. Calculate its frequency. Identify the region of the electromagnetic spectrum to which it belongs.
3. Explain why X-rays are used in medical diagnosis but gamma rays are generally not preferred for routine imaging.
4. During a disaster, communication systems based on radio waves continue to operate even when mobile networks fail. Explain why radio waves are suitable for long-distance communication.
5. A microwave signal of frequency 12 GHz is used for satellite communication. Calculate its wavelength. State one advantage of using microwaves for satellite communication.

Answers

1. Differences: (i) Electromagnetic waves do not require a material medium, whereas mechanical waves do. (ii) Electromagnetic waves are produced by oscillating electric and magnetic fields, whereas mechanical waves are produced by particle vibrations. (iii) Electromagnetic waves can travel through vacuum, whereas mechanical waves cannot.
2. Given wavelength, $\lambda = 3 \times 10^{-7} \text{ m}$. Using $v = c/\lambda = (3 \times 10^8)/(3 \times 10^{-7}) = 1 \times 10^{15} \text{ Hz}$. The wave belongs to the ultraviolet region.
3. X-rays have suitable penetrating power for imaging bones and tissues without causing excessive damage. Gamma rays are much more energetic and can cause severe damage to living cells, making them unsuitable for routine diagnosis.
4. Radio waves have long wavelengths and can diffract around obstacles and follow the curvature of the Earth. Hence they are effective for long-distance communication, especially during emergencies.

Long Answer Questions

1. (a) State any two properties of electromagnetic waves.
 (b) Arrange the following electromagnetic waves in increasing order of wavelength: Gamma rays, Infrared rays, X-rays, Radio waves.
 (c) Write one application each of X-rays and Infrared rays.

2. (a) Why are electromagnetic waves called transverse waves?
 (b) Draw the sketch showing electric field, magnetic field, and direction of propagation of an electromagnetic wave.
 (c) State the direction of magnetic field if the electric field oscillates along x-axis and the wave propagates along z-axis.
3. (a) State the relation between wavelength, frequency, and velocity of an electromagnetic wave.
 (b) An electromagnetic wave has frequency 5×10^{14} Hz. Calculate its wavelength.
 (c) Name the region of electromagnetic spectrum to which this wave belongs.
4. (a) Why are microwaves used in satellite communication? State any two reasons.
 (b) Why are radio waves suitable for long-distance communication?
 (c) Mention one application of microwaves other than communication.
5. (a) State any two harmful effects of ultraviolet radiation.
 (b) Why are ultraviolet rays still used in hospitals?
 (c) Name the electromagnetic waves used in sterilization and explain why they are suitable.

Answers

1. (a) Electromagnetic waves are transverse waves and can travel through vacuum.
 (b) Increasing order of wavelength: Gamma rays < X-rays < Infrared rays < Radio waves.
 (c) X-rays are used in medical diagnosis; Infrared rays are used in remote controls and thermal imaging.
2. (a) Electromagnetic waves are called transverse because electric and magnetic fields oscillate perpendicular to the direction of propagation.
 (b) Electric field, magnetic field, and propagation direction are mutually perpendicular.
 (c) If electric field is along x-axis and propagation is along z-axis, magnetic field oscillates along y-axis.
3. (a) Relation: $c = v\lambda$
 (b) $\lambda = c/v = (3 \times 10^8)/(5 \times 10^{14}) = 6 \times 10^{-7} \text{ m} = 600 \text{ nm}$.
 (c) The wave belongs to the visible region.
4. (a) Microwaves are used in satellite communication because they penetrate the atmosphere easily and are highly directional.
 (b) Radio waves can diffract around obstacles and travel long distances.
 (c) Microwaves are also used in radar systems and microwave ovens.
5. (a) Harmful effects of ultraviolet radiation: skin cancer and eye damage.
 (b) Ultraviolet rays are used in hospitals because they kill bacteria and microorganisms.
 (c) Ultraviolet waves are used for sterilization due to their germicidal action.

Practice questions

1. (a) Why are X-rays used in medical diagnosis?
 (b) Why are gamma rays not preferred for routine medical imaging?
 (c) State one use of gamma rays in medicine.
2. (a) Explain why infrared waves are used in TV remote controls.
 (b) During foggy conditions, infrared cameras work better than visible light cameras. Explain

why.

(c) Name one other application of infrared radiation.

3. (a) A radio station broadcasts waves of wavelength 25 m. Calculate its frequency.

(b) Name the region of electromagnetic spectrum corresponding to these waves.

(c) State one characteristic of these waves that makes them useful for communication.

4. What is displacement current? Obtain an expression for displacement current between the plates of a charging capacitor. Show that the displacement current in the capacitor equals the conduction current in the connecting wires.

Answers

1. (a) X-rays have suitable penetrating power and help image bones and tissues.

(b) Gamma rays are highly energetic and can damage living cells.

(c) Gamma rays are used in cancer treatment (radiotherapy).

2. (a) Infrared waves are used in remote controls because they are suitable for short-range communication.

(b) Infrared waves undergo less scattering in fog compared to visible light.

(c) Infrared radiation is also used in thermal imaging and night vision devices.

3. (a) Frequency $\nu = c/\lambda = (3 \times 10^8)/25 = 1.2 \times 10^7$ Hz.

(b) These waves belong to the radio wave region.

(c) Radio waves are useful for communication because they can travel large distances and diffract around obstacles.

4. Displacement current is the current equivalent arising due to the time-varying electric flux in a region where there is no conduction current (like the gap between capacitor plates).

Case Study 1: Development of Electromagnetic Waves

James Clerk Maxwell proposed that changing electric and magnetic fields can generate each other and travel through space as electromagnetic waves. Heinrich Hertz experimentally produced these waves later, while Jagdish Chandra Bose and Guglielmo Marconi contributed significantly to wireless communication systems.

Questions:

(i) Arrange the following EM waves in increasing order of frequency:

(a) Microwaves < Infrared < Ultraviolet < Gamma rays

(b) Gamma rays < Ultraviolet < Infrared < Microwaves

(c) Ultraviolet < Infrared < Microwaves < Gamma rays

(d) Gamma rays < Microwaves < Infrared < Ultraviolet

(ii) Visible light is an example of:

(a) Electromagnetic waves

(b) Mechanical waves

(c) Longitudinal waves

(d) Magnetic waves

(iii) Calculate the frequency of an EM wave of wavelength 500 nm.

(a) 600 Hz (b) 500 Hz (c) 167 Hz (d) 15 Hz

(iv) The electric and magnetic field vectors in an EM wave are inclined at:

(a) 180° (b) 120° (c) 90° (d) 45°

Answers: (i) a (ii) a (iii) a (iv) c

1. Radio waves are generated by accelerating charges in antennas, microwaves by magnetrons, infrared waves by hot bodies, and ultraviolet rays by extremely hot objects like the Sun.

(i) Solar radiation mainly consists of:

- (a) Transverse electromagnetic waves (b) Longitudinal electromagnetic waves
 (c) Both transverse and longitudinal waves (d) None of these
- (ii) The greenhouse effect is mainly caused by:
 (a) Infrared rays (b) Ultraviolet rays (c) X-rays (d) Radio waves
- (iii) The ozone layer is important because:
 (a) It absorbs harmful ultraviolet radiation (b) It reduces greenhouse effect
 (c) It reflects radio waves (d) None of these
- (iv) Earth's atmosphere is richest in:
 (a) Ultraviolet rays (b) Infrared radiation (c) X-rays (d) Microwaves
- Answers:** (i) a (ii) a (iii) a (iv) b

Production of Electromagnetic Waves

According to Maxwell's theory, accelerating charges produce electromagnetic waves. Oscillating electric and magnetic fields continuously regenerate each other and propagate through space.

Questions:

- (i) Electromagnetic waves are produced by:
 (a) Accelerating charges (b) Stationary charges
 (c) Uniformly moving charges (d) None of these
- (ii) Light can travel through vacuum because of its:
 (a) Transverse nature (b) Electromagnetic nature
 (c) Longitudinal nature (d) Both (a) and (c)
- (iii) Find the wavelength of an EM wave of frequency 8.2×10^6 Hz.
 (a) 36.6 m (b) 18.8 m (c) 42.8 m (d) 58 m
- (iv) Infrared radiations have:
 (a) Shorter wavelength than UV rays (b) Longer wavelength than UV rays
 (c) Same wavelength as UV rays (d) No comparison possible
- Answers:** (i) a (ii) b (iii) a (iv) b

Applications of Electromagnetic Waves

Different electromagnetic waves are used in technology and healthcare. X-rays are used in airport security systems, while microwaves efficiently heat food containing water molecules.

Questions:

- (i) Which radiation is used in airport luggage scanning?
 (a) Gamma rays (b) X-rays (c) Microwaves (d) Infrared rays
- (ii) Gamma rays of wavelength 1×10^{-12} m have frequency:
 (a) 3×10^{20} Hz (b) 2×10^{12} Hz (c) 2.5×10^5 Hz (d) 3.3×10^{12} Hz
- (iii) Why do microwaves heat water-containing food efficiently?
 (a) Microwaves are heat waves (b) Infrared rays produce heating
 (c) Water molecules absorb microwave energy efficiently (d) Frequency has no effect
- (iv) Which EM wave has the longest wavelength?
 (a) X-rays (b) Gamma rays (c) Microwaves (d) Radio waves
- Answers:** (i) b (ii) a (iii) c (iv) d



ELECTROMAGNETIC WAVES

CLASS XII PHYSICS – FORMULA SHEET

CBSE 2026-27 (LATEST SYLLABUS)



1. MAXWELL'S EQUATIONS IN FREE SPACE

(i) Gauss's Law (Electric)

$$\oint \vec{E} \cdot d\vec{S} = \frac{Q_{\text{encl}}}{\epsilon_0}$$

(ii) Gauss's Law (Magnetic)

$$\oint \vec{B} \cdot d\vec{S} = 0$$

(iii) Faraday's Law of Electromagnetic Induction

$$\oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$$

(iv) Ampere-Maxwell Law

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{encl}} + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$$

$$\text{where, } \Phi_E = \int \vec{E} \cdot d\vec{S}$$

$$\text{Displacement Current : } I_D = \epsilon_0 \frac{d\Phi_E}{dt}$$

2. BASIC RELATIONS FOR ELECTROMAGNETIC WAVES

• Speed of EM wave in vacuum (c):

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 3.00 \times 10^8 \text{ m s}^{-1}$$

• Speed in a medium (v):

$$v = \frac{1}{\sqrt{\mu \epsilon}} = \frac{c}{\sqrt{\mu_r \epsilon_r}} = \frac{c}{n}$$

where, $n = \sqrt{\mu_r \epsilon_r}$ (Refractive index)

• Wave equation:

$$c = v\lambda \quad \text{or} \quad v = v\lambda$$

• Wavelength: $\lambda = \frac{v}{\nu}$

• Frequency: $\nu = \frac{v}{\lambda}$

• Time period: $T = \frac{1}{\nu}$

• Wave number: $k = \frac{2\pi}{\lambda}$

• Angular frequency: $\omega = 2\pi\nu = \frac{2\pi}{T}$

3. NATURE OF EM WAVES

- Electromagnetic waves are transverse.
- $\vec{E} \perp \vec{B} \perp$ direction of propagation ($\vec{k}$)
- Electric and magnetic fields are in phase.
- Amplitudes are related by:

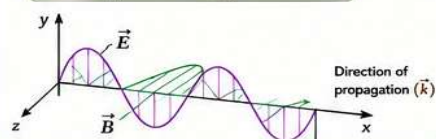
$$\frac{E_0}{B_0} = c \quad \text{or} \quad E_0 = cB_0$$

• Average energy density:

$$u = \frac{1}{2} \epsilon_0 E_0^2 + \frac{1}{2\mu_0} B_0^2 \quad (= \epsilon_0 E_0^2)$$

• Average Poynting vector (intensity):

$$\langle \vec{S} \rangle = \frac{1}{\mu_0} E_0 B_0 = \frac{E_0^2}{\mu_0 c} = \epsilon_0 c E_0^2 \quad (\text{W/m}^2)$$



4. ENERGY, MOMENTUM & PRESSURE

• Energy density (u): $u = \epsilon_0 E_0^2 = \frac{B_0^2}{\mu_0}$

• Energy flux / Intensity (I):

$$I = c u = \epsilon_0 c E_0^2 = \frac{c B_0^2}{\mu_0} \quad (\text{W/m}^2)$$

• Momentum density (g):

$$g = \frac{I}{c^2} = \frac{u}{c} \quad (\text{kg m}^{-2} \text{ s}^{-1})$$

• Radiation pressure (P) on a perfectly absorbing surface:

$$P = \frac{I}{c}$$

• Radiation pressure on a perfectly reflecting surface:

$$P = \frac{2I}{c}$$

5. PLANE ELECTROMAGNETIC WAVE (EQNS)

A wave travelling in +z direction:

$$\vec{E}(z, t) = E_0 \sin(\omega t - kz) \hat{i}$$

$$\vec{B}(z, t) = B_0 \sin(\omega t - kz) \hat{j}$$

where, $k = \frac{2\pi}{\lambda}$, $\omega = 2\pi\nu$, $E_0 = cB_0$

Electric field wave equation:

$$\frac{\partial^2 \vec{E}}{\partial z^2} = \mu_0 \epsilon_0 \frac{\partial^2 \vec{E}}{\partial t^2}$$

Magnetic field wave equation:

$$\frac{\partial^2 \vec{B}}{\partial z^2} = \mu_0 \epsilon_0 \frac{\partial^2 \vec{B}}{\partial t^2}$$

6. ELECTROMAGNETIC SPECTRUM

Radiation	Frequency (Hz)	Wavelength (m)
Radio waves	10^4 to 10^8	$> 10^{-1}$
Microwaves	10^8 to 10^{12}	10^{-1} to 10^{-3}
Infrared	10^{12} to 4×10^{14}	10^{-3} to 7×10^{-7}
Visible	4×10^{14} to 7.5×10^{14}	7×10^{-7} to 4×10^{-7}
Ultraviolet	7.5×10^{14} to 10^{16}	4×10^{-7} to 10^{-8}
X-rays	10^{16} to 10^{19}	10^{-8} to 10^{-11}
Gamma rays	10^{19} to 10^{24}	$< 10^{-11}$

Order of Increasing Frequency (ν) $\longrightarrow$

Radio	Microwave	Infrared	Visible	UV	X-ray	Gamma
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Order of Increasing Energy ($E = h\nu$) $\longrightarrow$

7. QUANTUM NATURE (PHOTON)

• Energy of photon: $E = h\nu = \frac{hc}{\lambda}$

• Momentum of photon: $p = \frac{h}{\lambda} = \frac{E}{c}$

• Planck's constant: $h = 6.626 \times 10^{-34} \text{ J s}$

• $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$

8. RELATIONS IN A MEDIUM

• Speed in medium: $v = \frac{c}{n}$

• Wavelength in medium: $\lambda_m = \frac{\lambda_0}{n}$

• Frequency remains same: $\nu_m = \nu_0$

• Wave impedance of medium: $Z = \sqrt{\frac{\mu}{\epsilon}} = \frac{Z_0}{n}$

where, $Z_0 = \sqrt{\frac{\mu_0}{\epsilon_0}} = \mu_0 c = 377 \Omega$

9. IMPORTANT CONSTANTS

- Speed of light in vacuum (c) = $3.00 \times 10^8 \text{ m s}^{-1}$
- Permittivity of free space (ϵ_0) = $8.854 \times 10^{-12} \text{ F m}^{-1}$
- Permeability of free space (μ_0) = $4\pi \times 10^{-7} \text{ H m}^{-1}$
- Impedance of free space (Z_0) = 377Ω
- Planck's constant (h) = $6.626 \times 10^{-34} \text{ J s}$
- Elementary charge (e) = $1.602 \times 10^{-19} \text{ C}$
- 1 eV = $1.602 \times 10^{-19} \text{ J}$

10. POINTS TO REMEMBER

- ✓ EM waves do not require a material medium to propagate.
- ✓ They carry energy and momentum.
- ✓ They are transverse and can be polarized.
- ✓ In vacuum, all EM waves travel with the same speed (c).
- ✓ $\vec{E}$ and $\vec{B}$ are always perpendicular to each other and to direction of propagation.
- ✓ Electric field component is responsible for all optical phenomena.
- ✓ Produced by accelerating charges.



11. DIMENSIONS (For Quick Check)

$$[\epsilon_0] = [\text{F m}^{-1}] = [\text{M}^{-1} \text{L}^{-3} \text{T}^4 \text{A}^2]$$

$$[\mu_0] = [\text{H m}^{-1}] = [\text{MLT}^{-2} \text{A}^{-2}]$$

$$[E_0] = [B_0] = [\text{MLT}^{-3} \text{A}^{-1}]$$

$$[I] = [\text{W m}^{-2}] = [\text{MLT}^{-3}]$$

$$[u] = [\text{J m}^{-3}] = [\text{ML}^{-1} \text{T}^{-2}]$$

$$[h] = [\text{J s}] = [\text{ML}^2 \text{T}^{-1}]$$

12. HANDY DERIVED RESULTS

- $c^2 = \frac{1}{\mu_0 \epsilon_0}$
- $E_0 = cB_0$
- $I = \frac{E_0 B_0}{\mu_0} = cu$
- $p = \frac{I}{c^2}$ (momentum density)
- $P_{\text{abs}} = \frac{I}{c}$, $P_{\text{ref}} = \frac{2I}{c}$



EM WAVES – KEY IDEA

A time-varying electric field produces a magnetic field, and a time-varying magnetic field produces an electric field. This self-sustaining process creates electromagnetic waves that travel through space.

