PART–1:
Original, exam-oriented notes for CBSE Board + NEET + JEE

8.1 Introduction

Electromagnetic waves are waves consisting of **time-varying electric and magnetic fields** which propagate through space.

Unlike mechanical waves, electromagnetic waves **do not require a material medium** for their propagation. Therefore, they can travel through vacuum.

Light is one example of an electromagnetic wave. Radio waves, microwaves, infrared radiation, ultraviolet radiation, X-rays and gamma rays are also electromagnetic waves.

Important idea

An electromagnetic wave is associated with:

- an electric field E,
- a magnetic field B,
- propagation of the wave.

The electric and magnetic fields oscillate perpendicular to each other and also perpendicular to the direction of propagation.

8.2 Displacement Current

The concept of displacement current was introduced by **James Clerk Maxwell**.

Consider a capacitor being charged through a conducting wire.

In the conducting wire, there is an ordinary conduction current.

However, between the two plates of the capacitor, there is no physical flow of charge from one plate to the other through the dielectric/vacuum gap.

Still, the electric field between the plates is changing with time.

Maxwell proposed that a changing electric field produces an effect equivalent to a current. This is called **displacement current**.

Displacement current

For a changing electric flux,

$$\boxed{I_d = \epsilon_0 \frac{d\varphi_E}{dt}}$$

Where:

- I_d = displacement current
- E_0 = permittivity of free space
- Φ_E = electric flux

Word Equation

Displacement current is proportional to the rate of change of electric flux.

8.3 Conduction Current vs Displacement Current

Conduction Current	Displacement Current
Associated with actual movement of charges	Associated with changing electric field
Exists in conducting media	Can exist in vacuum/dielectric
Example: current in a wire	Example: charging capacitor gap
Denoted by I	Denoted by Id

Exam Point

In a charging capacitor:

- Conduction current exists in the connecting wires;
- Displacement current exists in the gap between the plates.

For an ideal charging capacitor, the magnitudes of the conduction current and displacement current are equal.

8.4 Electric Flux

Electric flux through a surface is a measure of the electric field passing through that surface.
For a uniform electric field,

$$\varphi_E = EA\cos\theta$$

Where:

- E = electric field,
- A = area of the surface,
- θ = angle between electric field and the normal to the surface.

Therefore,

$$I_d = \epsilon_0 \frac{d\varphi_E}{dt}$$

For a changing electric field over a fixed area,

$$\boxed{I_d = \epsilon_0 A \frac{dE}{dt}}$$

When the field is perpendicular to the surface

8.5 Maxwell's Contribution

Maxwell combined the ideas of electric and magnetic fields and predicted that:

A changing electric field can produce a magnetic field, and a changing magnetic field can produce an electric field.

This mutual generation of electric and magnetic fields makes possible the propagation of electromagnetic waves.

This was one of the major theoretical achievements of classical electromagnetism.

8.6 Production of Electromagnetic Waves

Suppose an electric charge is accelerated.

An accelerating charge produces a changing electric field.

The changing electric field produces a changing magnetic field.

The changing magnetic field in turn produces a changing electric field.

Thus, electromagnetic disturbances can propagate through space.

Key point

Accelerated charges are sources of electromagnetic radiation.

A charge moving with constant velocity does not radiate electromagnetic waves merely because it is moving.

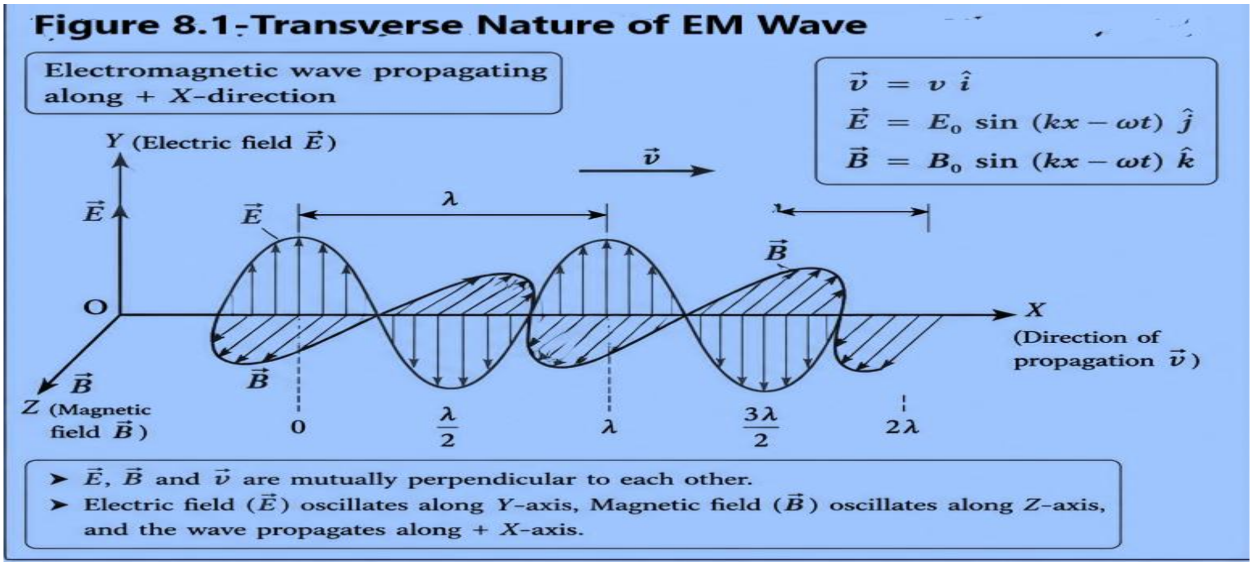
8.7 Nature of Electromagnetic Waves

Electromagnetic waves are **transverse waves**.

For a wave travelling along the x-direction:

- electric field may oscillate along the y-direction;
- magnetic field may oscillate along the z-direction.

Thus, E⊥B and both are perpendicular to the direction of propagation.



- x-axis → direction of propagation
- y-axis → electric field E
- z-axis → magnetic field B

8.8 Main Characteristics of Electromagnetic Waves

1. No material medium required
Electromagnetic waves can propagate through vacuum.

2. Transverse in nature
The electric and magnetic fields are perpendicular to the direction of propagation.

3. Electric and magnetic fields are mutually perpendicular
E⊥B

4. Electric and magnetic fields are in phase
Their maxima and minima occur simultaneously at corresponding positions.

5. They carry energy
Electromagnetic waves transport energy from one region to another.

6. They carry momentum
Electromagnetic radiation can exert radiation pressure.

7. They travel with the speed of light in vacuum
$c \approx 3\times10^{8}\ ms^{-1}$

8. They can show wave phenomena

Depending on the situation, electromagnetic radiation can exhibit:

- reflection,
- refraction,

- interference,
- diffraction,
- polarization.

8.9 Speed of Electromagnetic Waves

In vacuum, the speed of electromagnetic waves is

$$\boxed{c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}}$$

Where:

- μ_0 = permeability of free space,
- ε_0= permittivity of free space.

Numerically,

$c \approx 3\times10^8\ ms^{-1}$

This theoretical result led Maxwell to identify electromagnetic waves with light.

8.10 Relation Between Electric and Magnetic Field

For an electromagnetic wave travelling through vacuum,

$$\boxed{E = cB}$$

Therefore,

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

Where, E is measured in Vm−1 and B in tesla.

NEET/JEE Tip

If E and B are given for an electromagnetic wave in vacuum, the quickest relation is:

$$c = \frac{E}{B}$$

8.11 Frequency and Wavelength

For every electromagnetic wave,

$$\boxed{c = f\lambda}$$

Where:

- c = speed of electromagnetic wave in vacuum,
- f = frequency,
- λ = wavelength.

Hence,

$$\boxed{\lambda = \frac{c}{f}}$$

And

$$\boxed{f = \frac{c}{\lambda}}$$

Important

When electromagnetic radiation travels from vacuum into a medium:

- frequency remains unchanged;
- speed changes (decreases)
- wavelength changes (decreases)

This is a very important **NEET/JEE conceptual point**.

8.12 Important Concept: What Changes When Light Enters Another Medium?

Suppose light enters glass from air.

Its:

- **frequency → unchanged**
- **speed → decreases**
- **wavelength → decreases**

Because

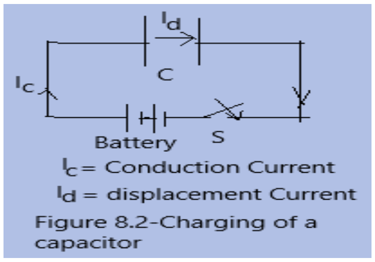
$$v = f\lambda$$

And, remains constant.

Therefore, for a fixed frequency.

$$\lambda \propto v$$

Charging capacitor showing conduction current and displacement current



Board / NEET / JEE Focus

CBSE Board:

Definitions, displacement current, characteristics of electromagnetic waves, transverse nature and basic relations.

NEET:

E= cB, c = fλ, displacement current and conceptual questions about frequency/speed/wavelength.

JEE:

Field orientation, changing-field concepts, displacement current and numerical application of electromagnetic-wave relations.

PART–2: Electromagnetic Spectrum, Energy, Momentum & Applications

8.13 Electromagnetic Spectrum

The **electromagnetic spectrum** is the complete range of electromagnetic radiation arranged according to their **frequency, wavelength or photon energy**.

The electromagnetic spectrum extends from:

Radio waves → Microwaves → Infrared → Visible → Ultraviolet → X-rays → Gamma rays

Order of increasing frequency

Radio < Microwave < IR < Visible < UV < X-ray < γ

Order of decreasing wavelength

Radio > Microwave > IR > Visible > UV > X-ray > γ

Thus:

Higher frequency means shorter wavelength.
Because

$$c = f\lambda$$

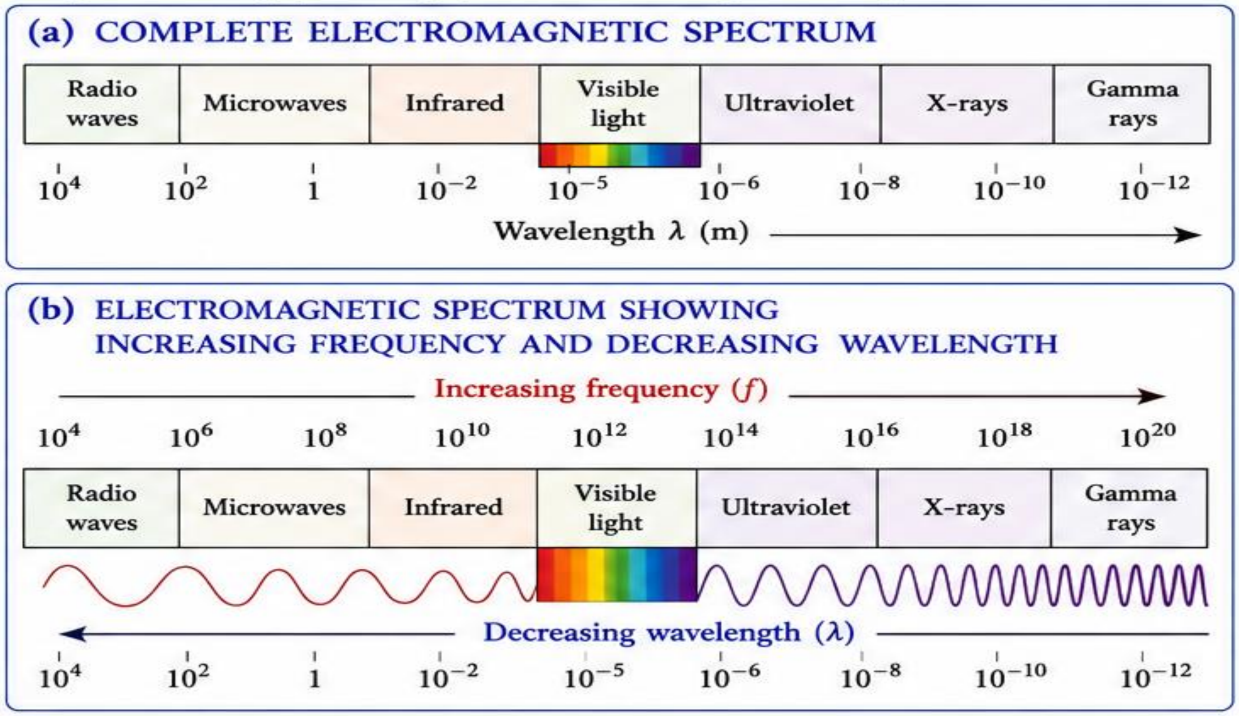
for electromagnetic radiation in vacuum.

8.14 Electromagnetic Spectrum — Quick Comparison

Radiation	Relative wavelength	Relative frequency	Important applications
Radio waves	Longest	Lowest	Radio/TV communication
Microwaves	Shorter than radio	Higher	Radar, satellite communication, microwave heating
Infrared	Shorter	Higher	Thermal imaging, remote controls
Visible light	Intermediate	Intermediate	Vision, optical instruments
Ultraviolet	Shorter	Higher	Sterilization, fluorescence
X-rays	Very short	Very high	Medical imaging
Gamma rays	Shortest	Highest	Cancer therapy, sterilization

Important: The boundaries between these regions are not perfectly sharp; their ranges overlap in different reference systems.

Figure 8.3 (a) and (b): Electromagnetic Spectrum



8.15 Radio Waves

Radio waves have comparatively **long wavelengths** and **low frequencies**.
They are generally produced by oscillating/accelerating charges in transmitting systems.

Applications

- Radio broadcasting
- Television communication
- Wireless communication
- Long-distance communication

Exam Point

Radio waves are particularly useful for communication because they can be generated, transmitted and detected efficiently over large distances.

8.16 Microwaves

Microwaves have shorter wavelengths and higher frequencies than ordinary radio waves.

Applications

1. Radar

Microwaves are used in radar systems for detecting and locating objects.

2. Satellite communication

They are widely used for satellite communication.

3. Microwave ovens

Microwaves interact with matter and can produce heating.

NEET Point
Radar applications depend on the ability of electromagnetic waves to travel, reflect from objects and return to the receiver.

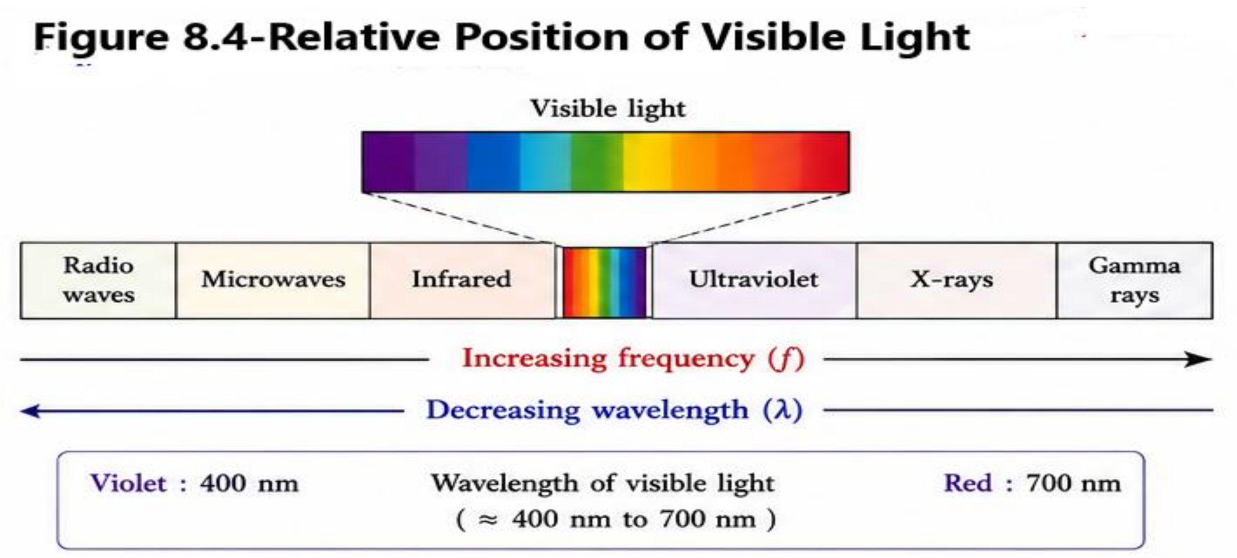
8.17 Infrared Radiation
Infrared radiation lies between microwaves and visible light. It is strongly associated with **thermal radiation** from objects.

Sources
Hot objects emit infrared radiation.

Applications
- Remote controls
- Thermal imaging
- Night vision systems
- Heat sensing
- Physiotherapy/heat treatment
- Industrial thermal monitoring

Important Concept

An object at ordinary temperature also emits electromagnetic radiation, with a significant part lying in the infrared region.

8.18 Visible Radiation


Visible light is the small portion of the electromagnetic spectrum that can be detected by the human eye.
Its approximate wavelength range is: 400 nm to 700 nm approximately.
The colours are arranged from shorter wavelength to longer wavelength as:

Violet→Indigo→Blue→Green→Yellow→Orange→Red

Important relationship

Violet has:

- shorter wavelength,
- higher frequency,

While red has:

- longer wavelength,
- lower frequency.

8.19 Ultraviolet Radiation

Ultraviolet (UV) radiation has a frequency higher than visible light. It has several important biological and technological applications.

Applications

- Sterilisation
- Disinfection
- Detection of fluorescent substances
- Photochemical processes

Important Point

Excessive exposure to UV radiation can be harmful to living tissues, particularly the skin and eyes.

8.20 X-Rays

X-rays have very short wavelengths and very high frequencies. They have significant penetrating ability.

Applications

1. Medical diagnosis

X-rays are used to obtain images of internal structures of the body.

2. Security scanning

They are used in scanning systems to examine luggage and packages.

3. Industrial applications

They can be used for detecting internal defects in materials.

NEET/JEE Point

X-rays have considerably higher frequency than ultraviolet radiation.

8.21 Gamma Rays

Gamma rays occupy the highest-frequency, shortest-wavelength region of the electromagnetic spectrum.

They are commonly associated with **nuclear and subatomic processes**.

Applications

- Cancer radiotherapy

- Sterilisation of medical equipment
- Certain industrial applications
- Scientific research

Important Point

Gamma rays possess very high photon energies.

8.22 Frequency–Wavelength–Energy Relationship

For electromagnetic radiation in vacuum,

$$c = f\lambda$$

The energy of a photon is

$$E = hf$$

Therefore,

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

Hence:

$$E \propto \frac{1}{\lambda}$$

So, among electromagnetic waves:

Higher frequency → higher photon energy → shorter wavelength.

8.23 Energy Transported by Electromagnetic Waves

Electromagnetic waves transport energy.

The energy is associated with their electric and magnetic fields.

The energy density of an electromagnetic field contains contributions from both fields.

For the electric field:

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

For the magnetic field:

$$u_B = \frac{1}{2}\left(\frac{B^2}{\mu_0}\right)$$

For an electromagnetic wave in vacuum, the electric and magnetic contributions are equal on average.

Thus,

$$\boxed{u_E = u_B}$$

and total energy density is

$$\boxed{u = u_E + u_B}$$

Try Yourself:

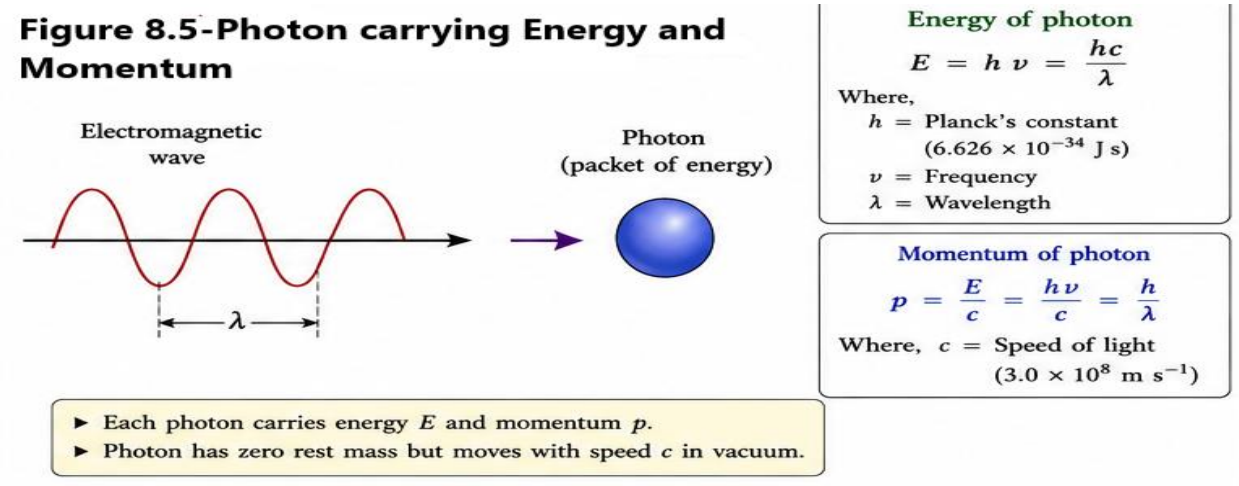
Q.1. The electric field varies with position and time $(x, t))$ is given as-

$$E(x, t)) = E_m \sin(kx - \omega t)$$

(a) In which direction the wave is propagating?

(b) Write the equation of magnetic wave

(c) What tis the wavelength and frequency of the wave?



8.24 Momentum of Electromagnetic Radiation

Electromagnetic radiation also carries momentum.
For a photon:

$$\boxed{p = \frac{E}{c}}$$

Where: p = momentum, E = photon energy, c = speed of light.
Using E = hf,

$$\boxed{p = \frac{hf}{c}}$$

Since

$$c = f\lambda$$

We obtain

$$\boxed{p = \frac{h}{\lambda}}$$

Very Important NEET/JEE Formula

8.25 Radiation Pressure

Since electromagnetic radiation carries momentum, it can exert pressure when it interacts with a surface.
For complete absorption, radiation pressure is approximately

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

Where I is intensity For complete reflection,

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

These relations are useful in higher-level conceptual problems.

8.26 Intensity of Electromagnetic Radiation

Intensity is the average energy transported per unit area per unit time.

$$\boxed{I = \frac{Energy}{Area \times time}}$$

Its SI unit is: Wm^{-2}

For an electromagnetic wave, intensity is proportional to the square of the amplitude of the electric field:

$$\boxed{I \propto {E_0}^2}$$

and also

$$\boxed{I \propto {B_0}^2}$$

Where E_0 and B_0 are peak field amplitudes.

8.27 Important Relationships for Revision

The following chain is extremely useful:

$$\boxed{c = f\lambda}$$

$$\boxed{E = hf}$$

Therefore,

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

And

$$\boxed{p = \frac{E}{c} = \frac{h}{\lambda}}$$

Thus:

$$\boxed{f \uparrow \Rightarrow \lambda \downarrow \Rightarrow E \uparrow}$$

8.28 Electromagnetic Spectrum — Memory Sequence

Remember:

R M I V U X G

Radio
Microwave
Infrared
Visible
Ultraviolet
X-rays
Gamma rays

From left to right:

$$\boxed{f \uparrow, E \uparrow, \lambda \downarrow}$$

Part-3: Board/NEET/JEE Focus + Quick Revision

Board + NEET + JEE Focus

CBSE Board

Focus on:

- characteristics of EM waves
- electromagnetic spectrum
- order of frequency/wavelength
- uses of different radiations
- displacement current
- transverse nature

The current CBSE syllabus specifically includes the spectrum and elementary facts about its uses.

NEET

Especially remember:

$c = f\lambda$ $E = hf$, $E = hc/\lambda$, $p = h/\lambda$ and the complete spectrum order.

JEE

Pay special attention to:

- relation between E and B,
- energy density,
- intensity,
- radiation pressure,
- photon energy and momentum,
- frequency/wavelength comparisons.

8.29 Most Important Properties — One-Page Revision

Electromagnetic waves:

1. Do not require a material medium.
2. Can propagate through vacuum.
3. Are transverse in nature.
4. Electric and magnetic fields are mutually perpendicular.
5. Both fields are perpendicular to the direction of propagation.
6. E and B fields are in phase.
7. They carry energy and momentum.

8. Their speed in vacuum is approximately 3×108 ms−1.
9. They are produced by accelerated charges.
10. They exhibit reflection, refraction, interference, diffraction and polarisation.

The CBSE syllabus specifically describes the transverse nature as a **qualitative idea** and includes the electromagnetic spectrum and elementary uses of its different regions.

8.30 Direction of Propagation

The direction of propagation of an electromagnetic wave is along the direction of the Poynting vector:

$$\boxed{\vec{S} = \frac{1}{\mu_0}\left(\vec{E} \times \vec{B}\right)}$$

Thus,

$$\boxed{\vec{S} \perp \vec{E}}$$

And

$$\boxed{\vec{S} \perp \vec{B}}$$

8.31 Poynting Vector

The Poynting vector represents the **rate of flow of electromagnetic energy per unit area**.

$$\boxed{\vec{S} = \frac{1}{\mu_0}\left(\vec{E} \times \vec{B}\right)}$$

Its SI unit is: Wm^{-2}
The magnitude is

$$\boxed{S = \frac{EB}{\mu_0}}$$

for mutually perpendicular E and B.

8.32 Electromagnetic Wave in Vacuum

For an electromagnetic wave travelling in vacuum:

$$\boxed{E = cB}$$

And

$$\boxed{c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}}$$

Therefore,

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

These are important formula-based relations.

8.33 Complete Electromagnetic Spectrum

Increasing wavelength

$$\boxed{\gamma < X - rays < Visible < IR < Microwaves < Radio}$$

Increasing frequency

$$\boxed{Radio < Microwaves < IR < Visible < X - rays < \gamma}$$

Increasing photon energy

$$\boxed{Radio < Microwaves < IR < Visible < X - rays < \gamma}$$

because

$$E = hf$$

8.34 Visible Spectrum

Approximate wavelength range:

$$\boxed{400\ nm < \lambda < 700nm}$$

From shorter wavelength to longer wavelength:

$$\boxed{V \to I \to B \to G \to Y \to O \to R}$$

Therefore:

Violet

- shorter wavelength
- higher frequency
- higher photon energy

Red

- longer wavelength
- lower frequency
- lower photon energy

8.35 Electromagnetic Spectrum — Important Uses

Radio Waves

Uses:

- radio broadcasting
- television communication
- wireless communication

Microwaves

Uses:

- radar
- satellite communication
- microwave heating

Infrared

Uses:

- remote controls
- thermal imaging
- heat sensing

Visible Light
Uses:
- vision
- photography
- optical instruments
- illumination

Ultraviolet
Uses:
- sterilisation
- disinfection
- fluorescence

X-rays
Uses:
- medical imaging
- security scanning
- detection of internal defects

Gamma Rays
Uses:
- radiotherapy
- sterilisation
- nuclear and scientific applications

8.36 Three Relationships You Must Remember
The entire chapter can be remembered around these three relationships:

Relation 1

$$\boxed{c = f\lambda}$$

Relation 2

$$\boxed{E = hf}$$

Relation 3

$$\boxed{p = \frac{h}{\lambda}}$$

From these:

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

And

$$\boxed{p = \frac{E}{c}}$$

8.37 Ultra-Quick Revision Table

Quantity	Key relation
Speed	$c = \frac{1}{\mu_0 \epsilon_0}$
EM fields	$E = cB$
Wave relation	$c = f\lambda$
Photon energy	$E = hf$
Energy–wavelength	$E = \frac{hc}{\lambda}$
Photon momentum	$p = \frac{h}{\lambda}$
Electric energy density	$u_E = \frac{1}{2}\epsilon_0 E^2$
Magnetic energy density	$u_B = \frac{1}{2}\left(\frac{B^2}{\mu_0}\right)$
Poynting vector	$\vec{S} = \frac{1}{\mu_0}(\vec{E} \times \vec{B})$
Displacement current	$I_d = \epsilon_0 \frac{d\varphi_E}{dt}$
Absorption pressure	$P = \frac{I}{c}$
Reflection pressure	$P = \frac{2I}{c}$

8.38 Board Examination — Most Expected Questions

Q1. What are electromagnetic waves? State any four characteristics.

Answer: Electromagnetic waves are propagating disturbances consisting of time-varying electric and magnetic fields. They do not require a material medium, are transverse, have mutually perpendicular electric and magnetic fields, and transport energy and momentum.

Q2. Write the electromagnetic spectrum in increasing order of frequency.

Answer:
Radio < Microwave < IR < Visible < UV < X-ray < γ

Q3. Write two uses each of microwaves, infrared rays and X-rays.

This is a very suitable short-answer preparation question because the official syllabus explicitly includes elementary uses of the spectrum regions.

8.39 NEET High-Yield Points

Remember these five without hesitation:

$$\boxed{E = cB}$$

$$\boxed{c = f\lambda}$$

$$\boxed{E = hf}$$

$$\boxed{p = \frac{h}{\lambda}}$$

$$\boxed{\vec{S} \| direction\ of\ propagation}$$

And:

frequency ↑ → wavelength ↓ → photon energy ↑

8.40 JEE Insight

For JEE-level preparation, the most useful extensions are:

1. Field-direction questions
2. E/B = c numerical problems
3. Photon-energy comparison
4. Photon-momentum comparison
5. Electromagnetic spectrum ordering
6. Intensity and field-amplitude relation
7. Radiation pressure
8. Poynting vector direction

8.41 Chapter 8 — Final One-Line Memory

Electromagnetic waves are transverse, self-propagating electric–magnetic disturbances that carry energy and momentum through space without requiring a material medium.