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Introduction

Key Points

- Maxwell identified inconsistency in Ampere's circuital law for magnetic field outside a capacitor with time-varying current.
- He introduced displacement current to resolve this inconsistency.
- Maxwell's equations unify electric and magnetic fields with their sources (charge and current densities).
- Hertz experimentally confirmed electromagnetic waves in 1885; Marconi used them for communication revolution.

Solved Examples

- **Ex 1:** Explain why displacement current is needed in Ampere's law.
  - Charging capacitor shows magnetic field discontinuity if only conduction current considered.
  - Displacement current term added to maintain continuity and satisfy Kirchhoff's law.

Practice Set

- Q1: What did Maxwell add to Ampere's law?
  - A) Magnetic flux
  - B) Displacement current
  - C) Electric charge
  - D) Electric flux
- Q2: Who experimentally demonstrated electromagnetic waves?
  - A) Maxwell
  - B) Marconi
  - C) Hertz
  - D) Faraday
- Q3: Maxwell's equations relate which of the following?
  - A) Only electric fields
  - B) Only magnetic fields
  - C) Electric and magnetic fields with charges and currents

- D) Only charges and currents

Answer Key

- Q1: B - Displacement current added to fix Ampere’s law inconsistency.
- Q2: C - Hertz demonstrated electromagnetic waves experimentally.
- Q3: C - Maxwell’s equations unify electric and magnetic fields with sources.

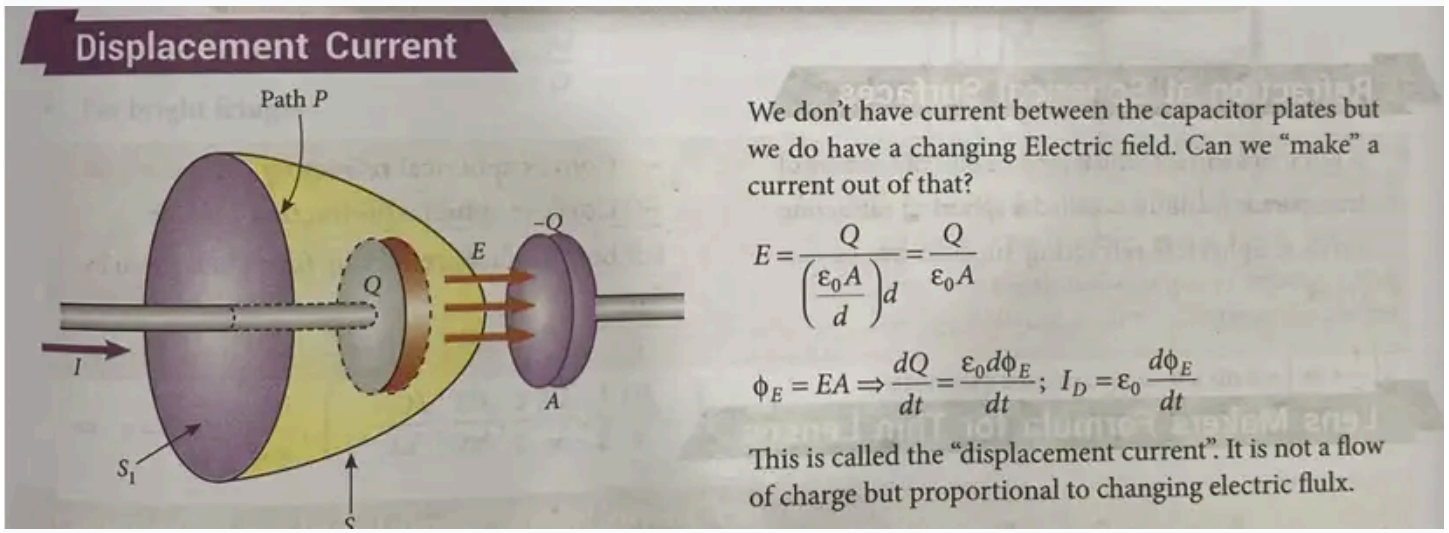
Memory Aids

- Displacement current = changing electric flux × permittivity.
- Maxwell’s equations unify electricity and magnetism.
- Hertz = electromagnetic waves proof.

Displacement Current

Concepts

- Changing electric field produces magnetic field (Maxwell’s insight).
- Displacement current $I_D = \varepsilon_0 \frac{d\Phi_E}{dt}$ acts like current in capacitor gap.
- Electric field between capacitor plates: $E = \frac{Q}{\varepsilon_0 A}$.
- Electric flux: $\Phi_E = EA$.
- No real charge flows through capacitor gap, but changing E creates displacement current.



Solved Examples

- **Ex 1:** Calculate displacement current if $\frac{d\Phi_E}{dt} = 5 \times 10^{-6}\ \text{Wb/s}$ and $\varepsilon_0 = 8.85 \times 10^{-12}\ \text{F/m}$.
  - $I_D = \varepsilon_0 \frac{d\Phi_E}{dt} = 8.85 \times 10^{-12} \times 5 \times 10^{-6} = 4.425 \times 10^{-17}\ \text{A}$

Practice Set

- Q1: Displacement current arises due to?
  - A) Constant electric field
  - B) Changing electric field
  - C) Magnetic field
  - D) Static charge
- Q2: Electric field between capacitor plates is given by?
  - A) $E = \frac{Q}{\varepsilon_0 A}$
  - B) $E = \frac{Q}{A}$
  - C) $E = \varepsilon_0 Q A$
  - D) $E = \frac{A}{Q}$
- Q3: Displacement current is?
  - A) Actual charge flow
  - B) Magnetic flux
  - C) Equivalent current due to changing electric field
  - D) Zero

Answer Key

- Q1: B - Displacement current arises from changing electric field.
- Q2: A - Electric field $E = \frac{Q}{\varepsilon_0 A}$.
- Q3: C - Displacement current behaves like current due to changing electric field.

Memory Aids

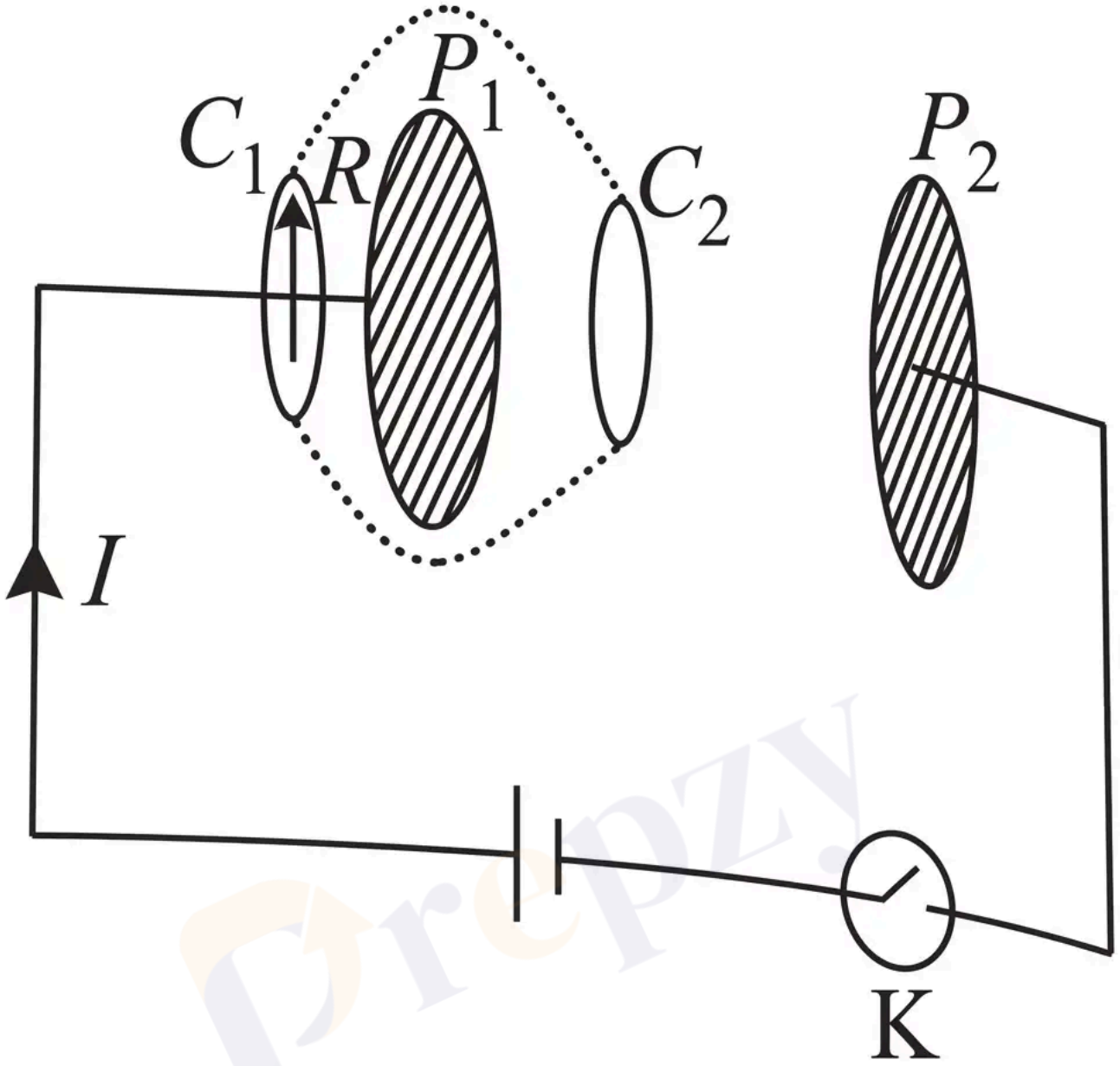
- Displacement current $I_D = \varepsilon_0 \frac{d\Phi_E}{dt}$.

- Electric flux $\Phi_E = EA$.
- No real charge crosses capacitor gap.

Inconsistency of Ampere's Circuital Law

Key Points

- Charging capacitor shows current I enters plate P_1 but no conduction current beyond it.
- Kirchhoff's first law seems violated as current appears to stop.
- Two loops C_1 (around wire) and C_2 (between plates) give different magnetic field results using Ampere's law.
- Loop C_1: $\oint \vec{B} \cdot d\vec{l} = \mu_0 I \neq 0$.
- Loop C_2: $\oint \vec{B} \cdot d\vec{l} = 0$ as conduction current is zero.
- This discontinuity contradicts continuous magnetic field observed physically.
- Maxwell proposed modifying Ampere's law to include displacement current.



Solved Examples

- **Ex 1:** Explain why magnetic field is discontinuous using Ampere's law.
  - Loop C_1 encloses conduction current I, magnetic field non-zero.
  - Loop C_2 encloses no conduction current, magnetic field zero.
  - Physical magnetic field is continuous, so Ampere's law incomplete.

Practice Set

- Q1: What causes inconsistency in Ampere's law?
  - A) Magnetic field discontinuity

    - B) Electric field discontinuity
    - C) Charge accumulation
    - D) Current continuity
- Q2: Loop C_2 in capacitor gap shows magnetic field?
    - A) Equal to $\mu_0 I$
    - B) Zero
    - C) Infinite
    - D) Negative
- Q3: Why is Kirchhoff's law apparently violated?
    - A) Current stops at capacitor plate
    - B) No displacement current considered
    - C) Magnetic field is zero
    - D) Electric field is constant

Answer Key

- Q1: A - Magnetic field discontinuity causes inconsistency.
- Q2: B - Loop C_2 has zero conduction current, so magnetic field zero.
- Q3: B - Displacement current missing causes Kirchhoff's law violation.

Memory Aids

- Ampere's law incomplete without displacement current.
- Magnetic field must be continuous.
- Displacement current fixes discontinuity.

Modified Ampere's Law by Maxwell

Key Points

- Maxwell modified Ampere's law to include displacement current I_D.
- Generalized law: $\oint \vec{B} \cdot d\vec{l} = \mu_0 [I + I_D]$.
- Displacement current: $I_D = \varepsilon_0 \frac{d\Phi_E}{dt}$, where $\Phi_E = EA$.
- This modification ensures magnetic field continuity and Kirchhoff's law validity.

Solved Examples

- **Ex 1:** Write generalized Ampere's law.
  - $\oint \vec{B} \cdot d\vec{l} = \mu_0[I + \varepsilon_0 \frac{d\Phi_E}{dt}]$

Practice Set

- Q1: Displacement current formula is?
  - A) $I_D = \varepsilon_0 \frac{d\Phi_E}{dt}$
  - B) $I_D = \mu_0 I$
  - C) $I_D = \frac{Q}{A}$
  - D) $I_D = 0$
- Q2: Generalized Ampere's law includes?
  - A) Only conduction current
  - B) Only displacement current
  - C) Both conduction and displacement currents
  - D) Neither
- Q3: Displacement current exists where?
  - A) Outside capacitor plates
  - B) Inside capacitor gap with changing electric flux
  - C) In resistors
  - D) In open air only

Answer Key

- Q1: A - Displacement current formula $I_D = \varepsilon_0 \frac{d\Phi_E}{dt}$.
- Q2: C - Generalized law includes both currents.
- Q3: B - Displacement current exists in capacitor gap with changing flux.

Memory Aids

- Generalized Ampere's law: $\oint \vec{B} \cdot d\vec{l} = \mu_0[I + I_D]$.
- Displacement current equals conduction current in magnitude.
- Ensures magnetic field continuity.

Consistency of Modified Ampere's Law

Key Points

- Loop C_1: $I_D = 0$, magnetic field due to conduction current only.
- Loop C_2: $I = 0$, magnetic field due to displacement current I_D.
- Magnetic field is continuous inside and outside capacitor plates.
- Displacement current magnitude equals conduction current $I_D = I$.
- Kirchhoff's first law holds with displacement current included.

Solved Examples

- **Ex 1:** Show $I_D = I$ using electric flux.
  - $\Phi_E = EA = \frac{q}{\varepsilon_0 A} \times A = \frac{q}{\varepsilon_0}$
  - $\frac{d\Phi_E}{dt} = \frac{1}{\varepsilon_0}\frac{dq}{dt} = \frac{I}{\varepsilon_0}$
  - $I_D = \varepsilon_0 \times \frac{I}{\varepsilon_0} = I$

Practice Set

- Q1: Displacement current magnitude compared to conduction current is?
  - A) Zero
  - B) Half
  - C) Equal
  - D) Double
- Q2: Kirchhoff's first law applies when?
  - A) Only conduction current present
  - B) Only displacement current present
  - C) Both conduction and displacement currents present
  - D) No current present
- Q3: Magnetic field continuity ensured by?
  - A) Conduction current only
  - B) Displacement current only
  - C) Both conduction and displacement currents
  - D) Neither

Answer Key

- Q1: C - Displacement current equals conduction current.
- Q2: C - Kirchhoff's law valid with both currents.
- Q3: C - Magnetic field continuity needs both currents.

Memory Aids

- Displacement current $I_D = I$.
- Kirchhoff's law valid with displacement current.
- Magnetic field continuous everywhere.

Maxwell's Equations

Key Points

- Four fundamental laws of electricity and magnetism.
- Explain production of electromagnetic waves.
- 1. Gauss's law for electricity: $\oint_S \vec{E} \cdot d\vec{S} = \frac{q_{inside}}{\varepsilon_0}$.
- 2. Gauss's law for magnetism: $\oint_S \vec{B} \cdot d\vec{S} = 0$.
- 3. Faraday's law: $\oint_l \vec{E} \cdot d\vec{l} = -\frac{d}{dt} \oint_S \vec{B} \cdot d\vec{S}$.
- 4. Modified Ampere's law: $\oint_l \vec{B} \cdot d\vec{l} = \mu_0 \left[I + \varepsilon_0 \frac{d}{dt} \oint_S \vec{E} \cdot d\vec{S} \right]$.
- Changing electric field produces magnetic field and vice versa.

Solved Examples

- **Ex 1:** Write Maxwell's four equations.
  - 1) $\oint_S \vec{E} \cdot d\vec{S} = \frac{q}{\varepsilon_0}$
  - 2) $\oint_S \vec{B} \cdot d\vec{S} = 0$
  - 3) $\oint_l \vec{E} \cdot d\vec{l} = -\frac{d}{dt} \oint_S \vec{B} \cdot d\vec{S}$
  - 4) $\oint_l \vec{B} \cdot d\vec{l} = \mu_0 \left[I + \varepsilon_0 \frac{d}{dt} \oint_S \vec{E} \cdot d\vec{S} \right]$

Practice Set

- Q1: Gauss’s law for electricity states?
  - A) Magnetic flux through closed surface is zero
  - B) Electric flux through closed surface equals charge inside divided by ε_0
  - C) Induced emf equals rate of change of magnetic flux
  - D) Magnetic field line integral equals current
- Q2: Faraday’s law relates induced emf to?
  - A) Electric flux change
  - B) Magnetic flux change
  - C) Charge change
  - D) Current change
- Q3: Modified Ampere’s law includes?
  - A) Only conduction current
  - B) Only displacement current
  - C) Both conduction and displacement currents
  - D) Neither

Answer Key

- Q1: B - Electric flux equals charge inside divided by permittivity.
- Q2: B - Induced emf proportional to rate of change of magnetic flux.
- Q3: C - Includes both conduction and displacement currents.

Memory Aids

- Gauss’s law (electric): flux = charge/ε_0.
- Gauss’s law (magnetic): flux = 0.
- Faraday: emf = -d(magnetic flux)/dt.
- Ampere-Maxwell: magnetic field line integral = μ_0(conduction + displacement current).

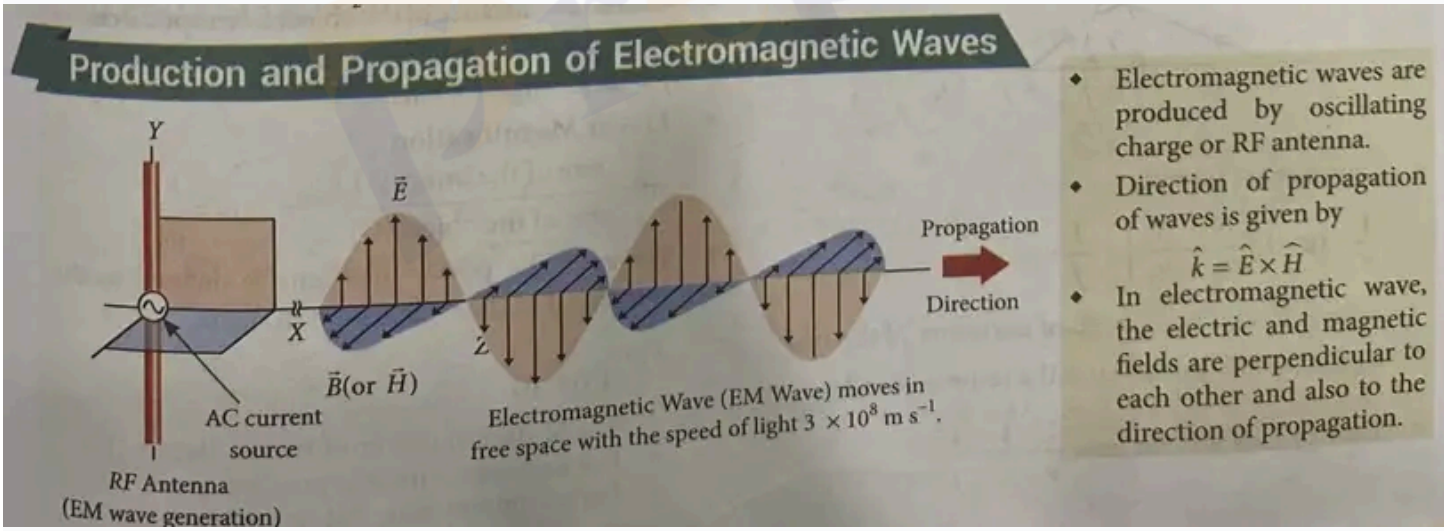
Electromagnetic Waves

Definition and Properties

- Electromagnetic waves have sinusoidal electric and magnetic fields oscillating perpendicular to each other and to the direction of wave propagation.
- Produced by alternating electric and magnetic fields as per Maxwell's equations.
- Frequency of the wave equals frequency of oscillating fields or accelerated charges.
- Carry energy and momentum through space at speed of light $c = 3 \times 10^8$ m/s in vacuum.

Production of Electromagnetic Waves

- Accelerated charges emit electromagnetic waves.
- Oscillating charges produce oscillating electric and magnetic fields regenerating each other.
- Energy of wave comes from energy of accelerating charge.



Solved Examples

- **Ex 1:** An antenna oscillates charges at frequency 1 MHz. What is the frequency of emitted EM wave?
  Solution: Frequency of EM wave = frequency of oscillation = 1 MHz.

Practice Set

- Q1: What causes electromagnetic waves?
  A. Stationary charges
  B. Uniform motion charges
  C. Accelerated charges
  D. None of these
- Q2: The electric and magnetic fields in an EM wave are:
  A. Parallel
  B. Perpendicular to each other and to wave direction
  C. Perpendicular only to each other
  D. Randomly oriented
- Q3: If an EM wave frequency is doubled, its wavelength:
  A. Doubles
  B. Halves
  C. Remains same
  D. Quadruples

Answer Key

- Q1: C - Accelerated charges produce EM waves.
- Q2: B - Fields are perpendicular to each other and direction of propagation.
- Q3: B - Wavelength inversely proportional to frequency.

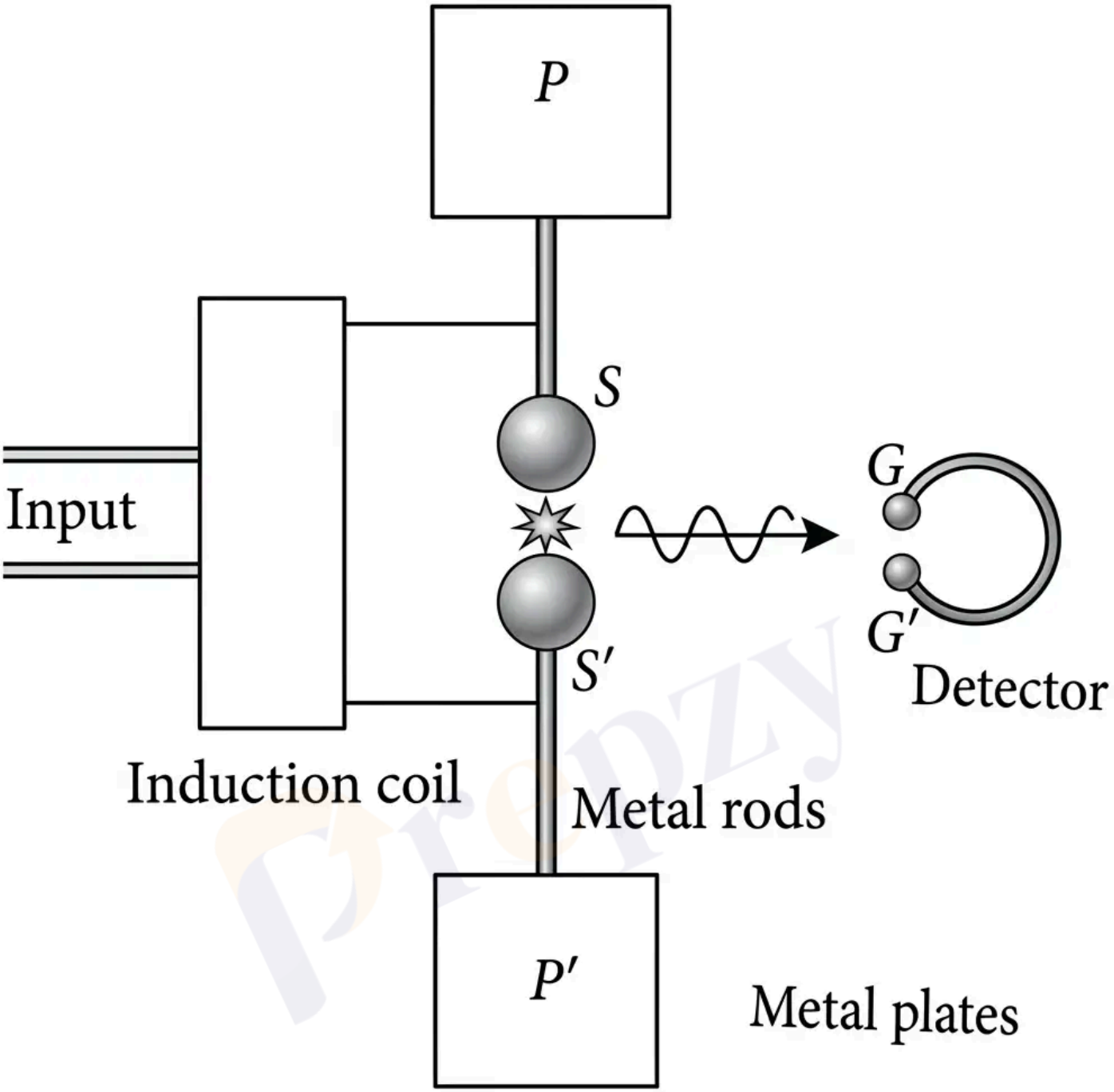
Memory Aids

- EM waves = Oscillating E and B fields at right angles.
- Accelerated charges = EM wave source.
- Frequency of wave = frequency of oscillation.

Hertz Experiment

Setup and Working

- Two metal plates connected to spheres and induction coil produce high-frequency oscillations.
- High potential ionizes air gap, causing sparks and oscillating electric field.
- Oscillating magnetic field perpendicular to electric field is produced.
- EM waves generated propagate through space and detected by a loop with gap producing sparks.



Solved Examples

- **Ex 1:** What causes the spark in Hertz's detector?
  Solution: EM waves induce emf in detector loop causing spark.

Practice Set

- Q1: What ionizes air in Hertz's experiment?
  A. Low potential difference
  B. High potential difference
  C. Magnetic field
  D. Electric current
- Q2: The resonant frequency in Hertz's setup depends on:
  A. Inductance and capacitance
  B. Resistance only
  C. Voltage only
  D. Current only
- Q3: What is the role of induction coil?
  A. Produce sparks
  B. Cause oscillations in spheres
  C. Detect EM waves
  D. None of these

Answer Key

- Q1: B - High potential difference ionizes air.
- Q2: A - Resonant frequency $\nu = \frac{1}{2\pi\sqrt{LC}}$.
- Q3: B - Induction coil causes oscillations in spheres.

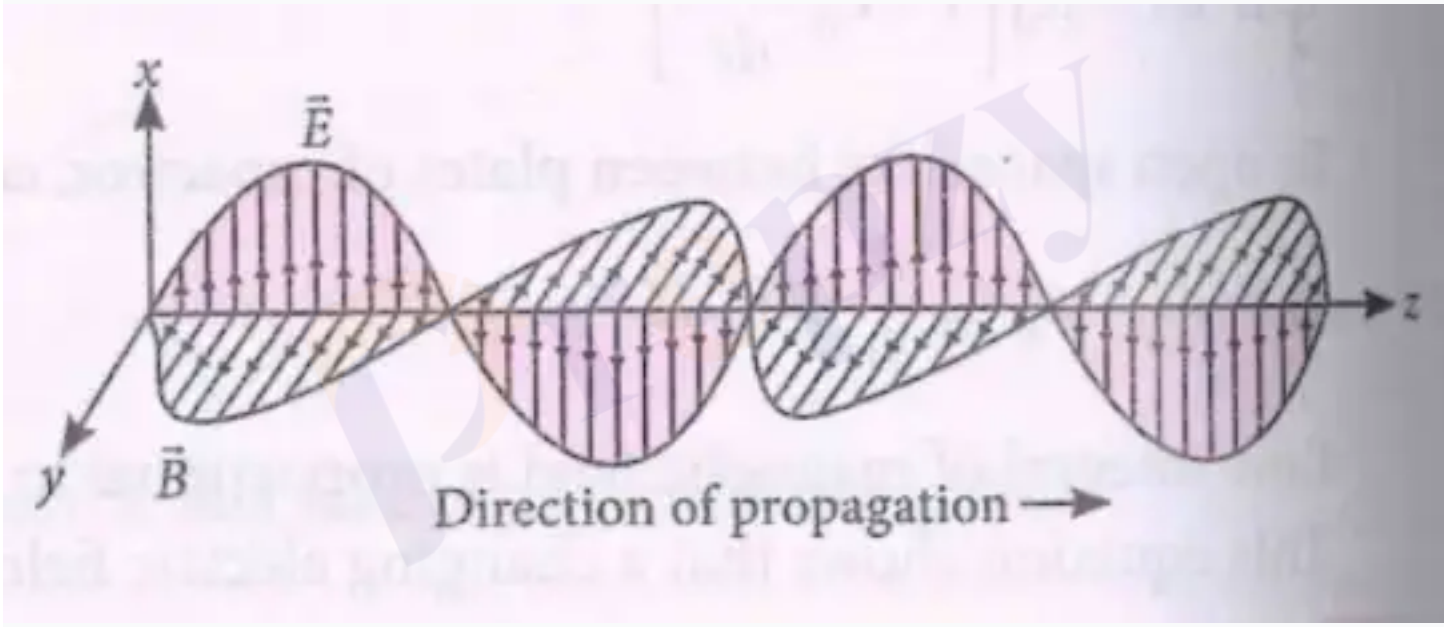
Memory Aids

- High voltage = air ionization = sparks.
- Resonant frequency depends on L and C.
- Induction coil drives oscillations.

Nature of Electromagnetic Waves

Wave Properties and Equations

- Electric field $E_x = E_0 \sin(kz - \omega t) = E_0 \sin[2\pi(z/\lambda - \nu t)]$.
- Magnetic field $B_y = B_0 \sin(kz - \omega t) = B_0 \sin[2\pi(z/\lambda - \nu t)]$.
- Relation: $\frac{E}{B} = c$ or $\frac{E_0}{B_0} = c$.
- Speed in vacuum: $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$.
- Speed in medium: $v = \frac{1}{\sqrt{\mu \epsilon}}$, where μ and ϵ are permeability and permittivity.
- EM waves are transverse; E and B fields perpendicular to each other and propagation direction.
- Carry energy and momentum; momentum $p = \frac{U}{c}$ where U is energy transferred.



Energy Density

- Energy density of electric field: $u_E = \frac{1}{2}\epsilon_0 E^2$.
- Energy density of magnetic field: $u_B = \frac{1}{2\mu_0} B^2$.
- Total energy density: $u = u_E + u_B = \frac{1}{2}\epsilon_0 E_{rms}^2 + \frac{1}{2\mu_0} B_{rms}^2$.
- Using $c = \frac{E_{rms}}{B_{rms}}$ and $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$, $u = \epsilon_0 E_{rms}^2 = \frac{B_{rms}^2}{\mu_0}$.

Solved Examples

- **Ex 1:** Calculate energy density if $E_{rms} = 100$ V/m.
  Solution: $u = \epsilon_0 E_{rms}^2 = 8.85 \times 10^{-12} \times (100)^2 = 8.85 \times 10^{-8}$ J/m³.

Practice Set

- Q1: The ratio $\frac{E}{B}$ in EM waves equals:
  A. Speed of sound
  B. Speed of light
  C. Frequency
  D. Wavelength
- Q2: The speed of EM wave in vacuum depends on:
  A. Permeability and permittivity
  B. Frequency
  C. Amplitude
  D. Medium temperature
- Q3: Energy density of magnetic field is:
  A. $\frac{1}{2}\epsilon_0 E^2$
  B. $\frac{1}{2\mu_0} B^2$
  C. $\epsilon_0 E^2$
  D. $\frac{B^2}{\epsilon_0}$

Answer Key

- Q1: B - $E/B = c$, speed of light.
- Q2: A - $c = 1/\sqrt{\mu_0 \epsilon_0}$.
- Q3: B - Magnetic energy density $= \frac{1}{2\mu_0} B^2$.

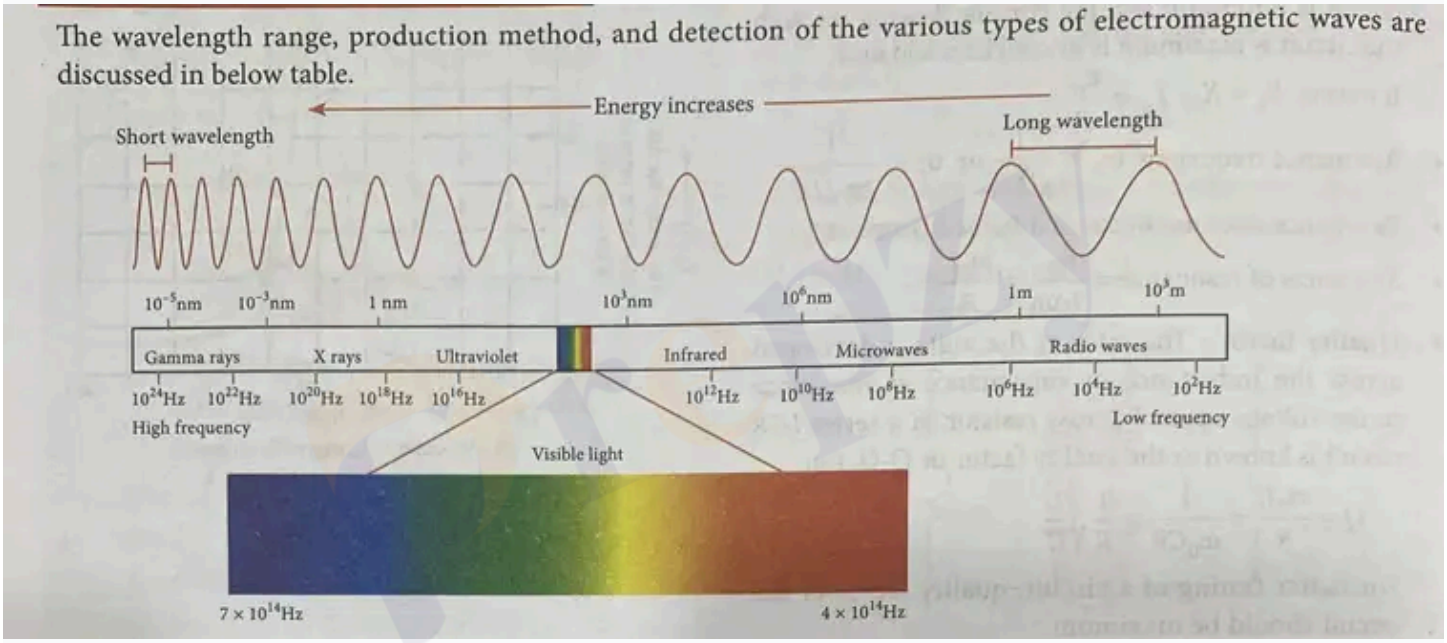
Memory Aids

- EM wave speed $c = 1/\sqrt{\mu_0 \epsilon_0}$.
- Energy density $u = \epsilon_0 E_{rms}^2 = B_{rms}^2/\mu_0$.
- Fields perpendicular and transverse wave.

Electromagnetic Spectrum

Overview

- Electromagnetic spectrum: orderly distribution of waves by frequency or wavelength.
- Wavelength range: gamma rays (shortest) to radio waves (longest).
- Frequency and energy increase as wavelength decreases.
- Visible light: small part of spectrum, wavelength 400–700 nm, frequency 4×10^{14} to 7×10^{14} Hz.
- Energy relation: $E = h\nu$ (energy proportional to frequency).



Solved Examples

- **Ex 1:** Calculate frequency of visible light with wavelength 500 nm.
  - Use $\nu = \frac{c}{\lambda}$, $c = 3 \times 10^{8}$ m/s, $\lambda = 500 \times 10^{-9}$ m.
  - $\nu = \frac{3 \times 10^{8}}{500 \times 10^{-9}} = 6 \times 10^{14}$ Hz.

Practice Set

- Q1: Which wave has the highest frequency?
  - A. Radio waves
  - B. Microwaves

    - C. X-rays
    - D. Gamma rays
- Q2: Visible light wavelength range is:
    - A. 400–700 nm
    - B. 700–1000 nm
    - C. 100–400 nm
    - D. 1–10 nm
- Q3: Energy of a photon is directly proportional to:
    - A. Wavelength
    - B. Frequency
    - C. Amplitude
    - D. Speed

Answer Key

- Q1: D. Gamma rays have the highest frequency and shortest wavelength.
- Q2: A. Visible light ranges from 400 to 700 nm wavelength.
- Q3: B. Energy $E = h\nu$ is proportional to frequency.

Memory Aids

- Frequency ↑ → Wavelength ↓ → Energy ↑
- Visible light colors: VIBGYOR (Violet shortest wavelength)
- Energy formula: $E = h\nu$

Radio Waves

Properties and Uses

- Frequency range: 500 kHz to 1000 MHz.
- Used in communication: radio, TV, cellular phones.

Solved Examples

- **Ex 1:** Find wavelength of radio wave with frequency 1 MHz.
  - $\lambda = \frac{c}{\nu} = \frac{3\times10^8}{1\times10^6} = 300$ m.

Practice Set

- Q1: Radio waves frequency range is:
  - A. 500 kHz to 1000 MHz
  - B. 1 MHz to 10 GHz
  - C. 100 MHz to 1 GHz
  - D. 10 kHz to 500 kHz
- Q2: Radio waves are mainly used for:
  - A. Cooking
  - B. Communication
  - C. Medical imaging
  - D. Sterilization
- Q3: Wavelength of a 500 kHz radio wave is:
  - A. 600 m
  - B. 300 m
  - C. 150 m
  - D. 1000 m

Answer Key

- Q1: A. Radio waves frequency range is 500 kHz to 1000 MHz.
- Q2: B. Radio waves are used in communication systems.
- Q3: A. $\lambda = \frac{3\times10^8}{5\times10^5} = 600$ m.

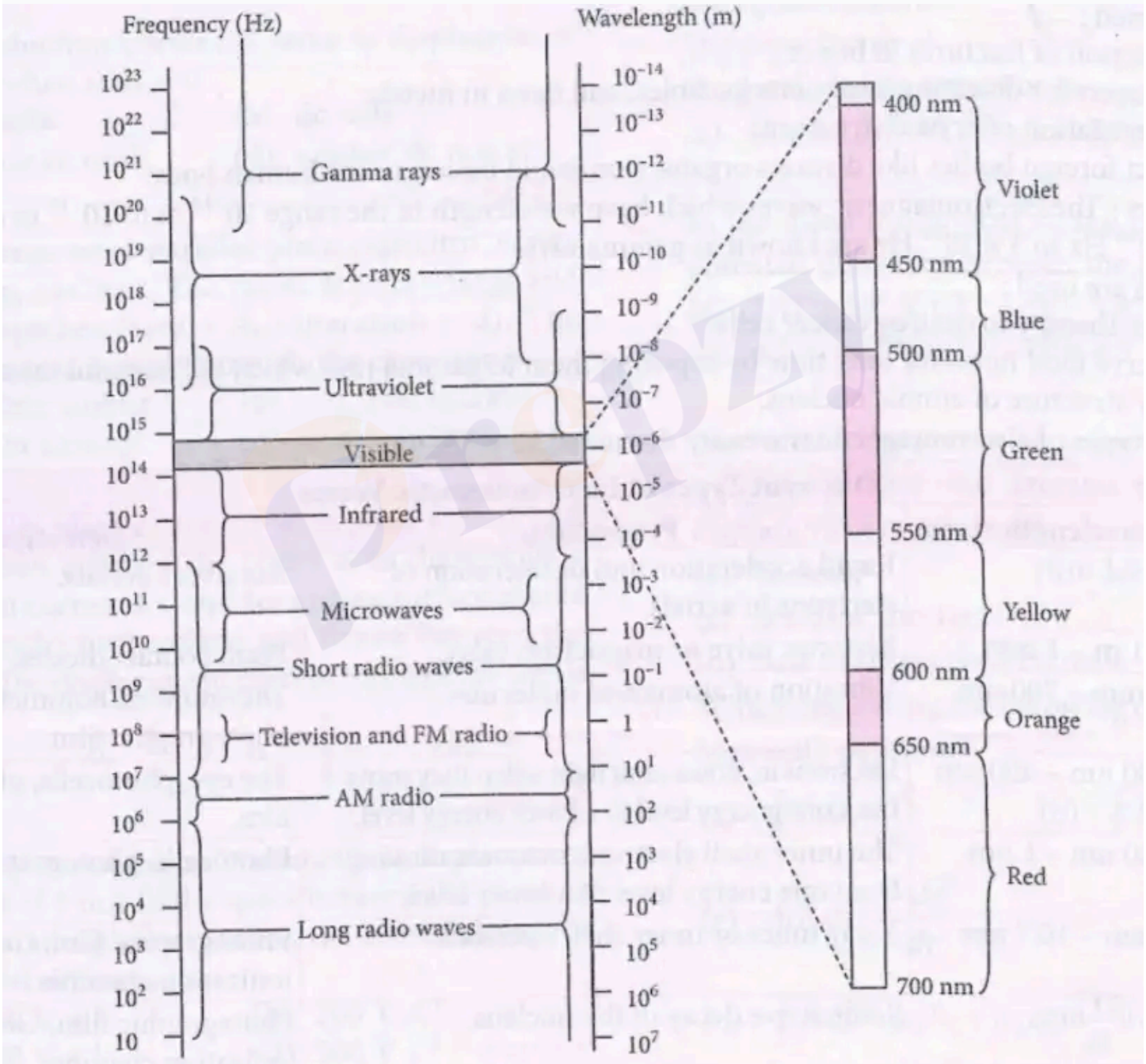
Memory Aids

- Radio waves = Communication waves
- Frequency range: 500 kHz to 1000 MHz
- Wavelength $\lambda = \frac{c}{\nu}$

Microwaves

Properties and Uses

- Shortest wavelength radio waves, smaller than other radio waves but longer than visible light.
- Used in radar for aircraft navigation and speed detection of moving objects.



Solved Examples

- **Ex 1:** Calculate wavelength of microwave with frequency 10 GHz.
  - $\lambda = \frac{3\times10^8}{10\times10^9} = 0.03$ m (3 cm).

Practice Set

- Q1: Microwaves are used in:
  - A. Communication only
  - B. Radar systems
  - C. X-ray imaging
  - D. Sterilization
- Q2: Microwave wavelength is generally:
  - A. Longer than radio waves
  - B. Shorter than visible light
  - C. Between radio waves and visible light
  - D. Same as infrared waves
- Q3: Radar using microwaves can detect speed of:
  - A. Stationary objects
  - B. Moving balls and automobiles
  - C. Only airplanes
  - D. Only ships

Answer Key

- Q1: B. Microwaves are used in radar systems.
- Q2: C. Microwaves have wavelengths between radio waves and visible light.
- Q3: B. Radar detects speed of moving balls and automobiles.

Memory Aids

- Microwaves = Radar + short radio waves
- Wavelength between radio and visible light
- Used for speed detection

Infrared Waves

Properties and Uses

- Frequency range: 3×10^{11} to 4×10^{14} Hz.
- Used in infrared lamps for physical therapy.
- Used in infrared detectors on Earth satellites.
- Used in LEDs for remote controls (TV, AC, CD players).
- Used in solar water heaters and cookers.
- Used in greenhouses to maintain temperature (greenhouse effect).
- Infrared radiation trapped by greenhouse gases maintains Earth's temperature.

Solved Examples

- **Ex 1:** Calculate wavelength of infrared wave with frequency 1×10^{13} Hz.
  - $\lambda = \frac{3 \times 10^8}{1 \times 10^{13}} = 3 \times 10^{-5}$ m (30 μm).

Practice Set

- Q1: Infrared waves frequency range is:
  - A. 3×10^{11} to 4×10^{14} Hz
  - B. 4×10^{14} to 7×10^{14} Hz
  - C. 8×10^{14} to 5×10^{17} Hz
  - D. 3×10^{18} to 3×10^{22} Hz
- Q2: Infrared waves are used in:
  - A. Physical therapy lamps
  - B. Water sterilization
  - C. X-ray imaging
  - D. Cancer therapy
- Q3: Greenhouse effect is caused by:
  - A. Visible light trapped by atmosphere
  - B. Infrared radiation trapped by greenhouse gases
  - C. Ultraviolet rays absorbed by ozone
  - D. Gamma rays heating Earth

Answer Key

- Q1: A. Infrared frequency range is 3×10^{11} to 4×10^{14} Hz.
- Q2: A. Infrared lamps are used in physical therapy.
- Q3: B. Infrared radiation trapped by CO_2 and water vapor causes greenhouse effect.

Memory Aids

- Infrared = Heat waves
- Frequency range: 3×10^{11} to 4×10^{14} Hz
- Greenhouse effect traps infrared radiation

Visible Rays

Properties and Uses

- Wavelength: 400 to 700 nm.
- Frequency: 4×10^{14} to 7×10^{14} Hz.
- Visible to human eye; colors from violet (shortest wavelength) to red (longest).
- Used in electric bulbs, tube lights, lasers, and cinema screens.

Solved Examples

- **Ex 1:** Find frequency of red light with wavelength 700 nm.
  - $\nu = \frac{3 \times 10^8}{700 \times 10^{-9}} = 4.29 \times 10^{14}$ Hz.

Practice Set

- Q1: Visible light wavelength range is:
  - A. 400–700 nm
  - B. 700–1000 nm
  - C. 100–400 nm

    - D. 1–10 nm
- Q2: Which color has the shortest wavelength?
    - A. Red
    - B. Green
    - C. Violet
    - D. Yellow
- Q3: Visible light frequency range is:
    - A. 4×10^{14} to 7×10^{14} Hz
    - B. 3×10^{11} to 4×10^{14} Hz
    - C. 8×10^{14} to 5×10^{17} Hz
    - D. 3×10^{18} to 3×10^{22} Hz

Answer Key

- Q1: A. Visible light wavelength is 400–700 nm.
- Q2: C. Violet has the shortest wavelength in visible spectrum.
- Q3: A. Frequency range is 4×10^{14} to 7×10^{14} Hz.

Memory Aids

- VIBGYOR for colors
- Wavelength increases from violet to red
- Frequency decreases from violet to red

Ultraviolet Rays

Properties and Uses

- Wavelength range: 0.6 to 400 nm.
- Frequency range: 8×10^{14} to 5×10^{17} Hz.
- Used for sterilizing surgical instruments and killing germs in water purifiers.
- Used in LASIK eye surgery and mineral fluorescence detection.
- Used in burglar alarms.

Solved Examples

- **Ex 1:** Calculate wavelength of UV ray with frequency 1×10^{15} Hz.
  - $\lambda = \frac{3 \times 10^8}{1 \times 10^{15}} = 3 \times 10^{-7}$ m (300 nm).

Practice Set

- Q1: Ultraviolet rays wavelength range is:
  - A. 0.6–400 nm
  - B. 400–700 nm
  - C. 700–1000 nm
  - D. 1–10 nm
- Q2: UV rays are used for:
  - A. Cooking
  - B. Sterilization
  - C. Communication
  - D. Heating
- Q3: UV rays frequency range is:
  - A. 8×10^{14} to 5×10^{17} Hz
  - B. 3×10^{11} to 4×10^{14} Hz
  - C. 4×10^{14} to 7×10^{14} Hz
  - D. 3×10^{18} to 3×10^{22} Hz

Answer Key

- Q1: A. UV wavelength range is 0.6–400 nm.
- Q2: B. UV rays sterilize instruments and kill germs.
- Q3: A. Frequency range is 8×10^{14} to 5×10^{17} Hz.

Memory Aids

- UV = Sterilization and fluorescence
- Wavelength shorter than visible light

- Frequency higher than visible light

X-rays

Properties and Uses

- Wavelength range: 10^{-4} nm to 10 nm.
- Used for bone fracture detection and metal flaw detection.
- Used in crystal structure investigation and detecting foreign bodies in humans.

Solved Examples

- **Ex 1:** Calculate frequency of X-ray with wavelength 0.1 nm.
  - $\nu = \frac{3\times10^{8}}{0.1\times10^{-9}} = 3 \times 10^{18}$ Hz.

Practice Set

- Q1: X-rays wavelength range is:
  - A. 10^{-4} nm to 10 nm
  - B. 400–700 nm
  - C. 0.6–400 nm
  - D. 500 kHz to 1000 MHz
- Q2: X-rays are used for:
  - A. Detecting fractures
  - B. Communication
  - C. Cooking
  - D. Sterilization
- Q3: X-rays help detect:
  - A. Mineral fluorescence
  - B. Foreign bodies in human body
  - C. Speed of moving objects
  - D. Greenhouse gases

Answer Key

- Q1: A. X-rays wavelength range is 10^{-4} nm to 10 nm.
- Q2: A. Used for detecting fractures in bones.
- Q3: B. Detect foreign bodies like stones and bullets.

Memory Aids

- X-rays = Medical imaging and metal inspection
- Wavelength very short, frequency very high
- Used to detect fractures and flaws

Gamma Rays

Properties and Uses

- Wavelength range: 10^{-14} m to 10^{-10} m.
- Frequency range: 3×10^{18} Hz to 3×10^{22} Hz.
- Used in cancer therapy to destroy cancer cells.
- Used to preserve food by killing microorganisms.
- Used to study atomic nucleus structure.

Different Types of Electromagnetic Waves

Type	Wavelength range	Production	Detection
Radio	> 0.1 m	Rapid acceleration and deceleration of electrons in aerials.	Receiver's aerials.
Microwave	0.1 m – 1 mm	Klystron valve or magnetron valve.	Point contact diodes.
Infrared	1 mm – 700 nm	Vibration of atoms and molecules.	Thermopiles, bolometer, infrared photographic film.
Light	700 nm – 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 – 1 nm	The inner shell electrons in atoms moving from one energy level to a lower level.	Photocells, photographic film.
X-rays	1 nm – 10^{-3} nm	X-ray tubes or inner shell electrons.	Photographic film, Geiger tubes, ionization chamber.
Gamma rays	< 10^{-3} nm	Radioactive decay of the nucleus.	Photographic film, Geiger tubes, ionization chamber.

Solved Examples

- **Ex 1:** Calculate frequency of gamma ray with wavelength 10^{-12} m.
  - $\nu = \frac{3\times10^{8}}{10^{-12}} = 3 \times 10^{20}$ Hz.

Practice Set

- Q1: Gamma rays wavelength range is:
  - A. 10^{-14} m to 10^{-10} m
  - B. 400–700 nm
  - C. 0.6–400 nm
  - D. 500 kHz to 1000 MHz
- Q2: Gamma rays are used for:
  - A. Cancer therapy
  - B. Communication
  - C. Cooking
  - D. Sterilization
- Q3: Gamma rays help in:
  - A. Studying atomic nucleus
  - B. Detecting fractures
  - C. Speed detection
  - D. Greenhouse effect

Answer Key

- Q1: A. Gamma rays have wavelength 10^{-14} m to 10^{-10} m.
- Q2: A. Used in cancer therapy to destroy cells.
- Q3: A. Used to study atomic nucleus structure.

Memory Aids

- Gamma rays = Highest frequency, shortest wavelength
- Used in cancer therapy and food preservation
- Frequency range: 3×10^{18} to 3×10^{22} Hz