Electromagnetic Waves

Class 12 Physics · Chapter 8 · CBSE

Handwritten Notes · Sequence: NCERT + S.L. Arora

How to use these notes: Topics follow the NCERT order. Extra topics from S.L. Arora are added where they fit and marked [S.L. Arora]. Boxed formulas are the ones to remember. 20 solved CBSE questions are at the end.

Index

1. Introduction
2. Displacement Current
3. Maxwell's Equations
4. Sources of EM Waves
5. Nature of EM Waves
6. Energy & Momentum
7. Electromagnetic Spectrum
8. Radio Waves & Microwaves
9. Infrared & Visible Light
10. UV, X-rays & Gamma Rays
11. Formula Sheet
12. 20 Previous Year Questions

1. Introduction NCERT 8.1

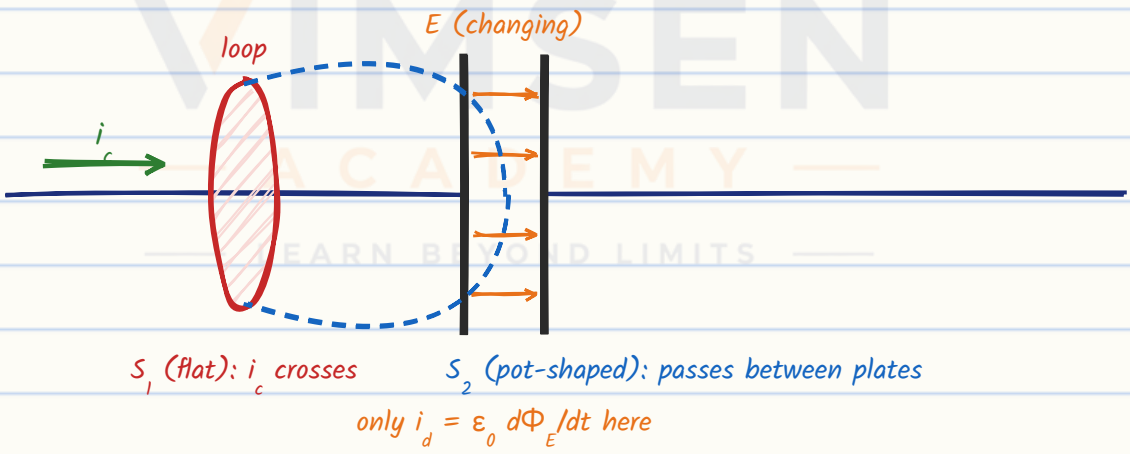
→ A changing magnetic field produces an electric field (Faraday). Maxwell asked: does a changing electric field produce a magnetic field? — Yes!

→ Maxwell (1864) combined all laws of electricity and magnetism into four equations and predicted **electromagnetic waves** travelling at the speed of light. So **light is an EM wave**.

→ **Hertz (1887)** produced and detected EM waves experimentally. **J.C. Bose (1895)** produced waves of 5–25 mm. **Marconi (1899)** sent them over long distances — the start of radio communication.

2. Displacement Current NCERT 8.2

The problem with Ampere's law



⇒ Ampere's law: $\oint B \cdot dl = \mu_0 i$. For the **same loop**:

⇒ Flat surface S_1 is crossed by the wire: $\oint B \cdot dl = \mu_0 i$

⇒ Pot-shaped surface S_2 passes between the plates, where no charge flows: $\oint B \cdot dl = 0$

⇒ **Contradiction!** Something must "flow" between the plates — it is the changing electric field.

Expression for displacement current

⇒ Between the plates: $E = q/(\varepsilon_0 A) \Rightarrow \Phi_E = E\,A = q/\varepsilon_0$

⇒ $d\Phi_E/dt = (1/\varepsilon_0)\, dq/dt = i/\varepsilon_0 \Rightarrow i = \varepsilon_0\, d\Phi_E/dt$

$$i_d = \varepsilon_0\, d\Phi_E/dt$$

Displacement current: the current that arises from a changing electric field (or electric flux). It produces a magnetic field just like conduction current.

Ampere–Maxwell law

$$\oint B \cdot dl = \mu_0 (i_c + \varepsilon_0\, d\Phi_E/dt) = \mu_0(i_c + i_d)$$

→ In the wires: $i_d = 0$, only i_c. Between the plates: $i_c = 0$, only i_d. And $i_c = i_d$, so the total current is continuous.

→ For a steady (DC) current or constant voltage, E does not change, so $i_d = 0$.

Conduction current	Displacement current [S.L. Arora]
Due to flow of charges	Due to a changing electric field
Exists in conductors	Exists in vacuum / dielectric (gap)
$i_c = dq/dt$	$i_d = \varepsilon_0\, d\Phi_E/dt$

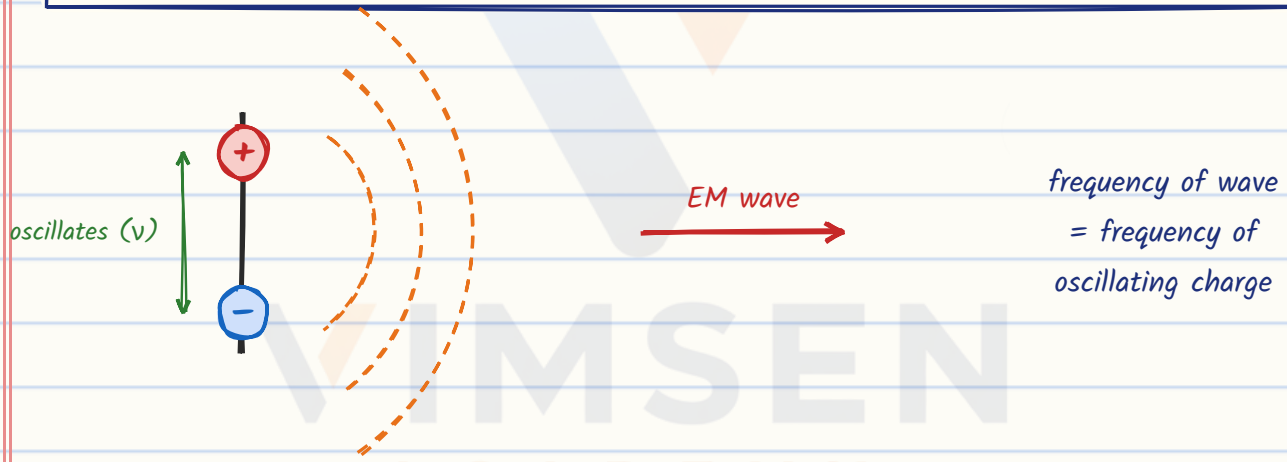
3. Maxwell's Equations NCERT 8.2

1.	$\oint E \cdot dA = Q/\varepsilon_0$	Gauss's law (electricity)
2.	$\oint B \cdot dA = 0$	Gauss's law (magnetism)
3.	$\oint E \cdot dl = -d\Phi_B/dt$	Faraday's law
4.	$\oint B \cdot dl = \mu_0 i_c + \mu_0\varepsilon_0\, d\Phi_E/dt$	Ampere–Maxwell law

Key idea: changing B makes E (eq. 3) and changing E makes B (eq. 4). Each keeps creating the other, so the fields travel through space by themselves — an **EM wave**.

4. Sources of Electromagnetic Waves NCERT 8.3.1

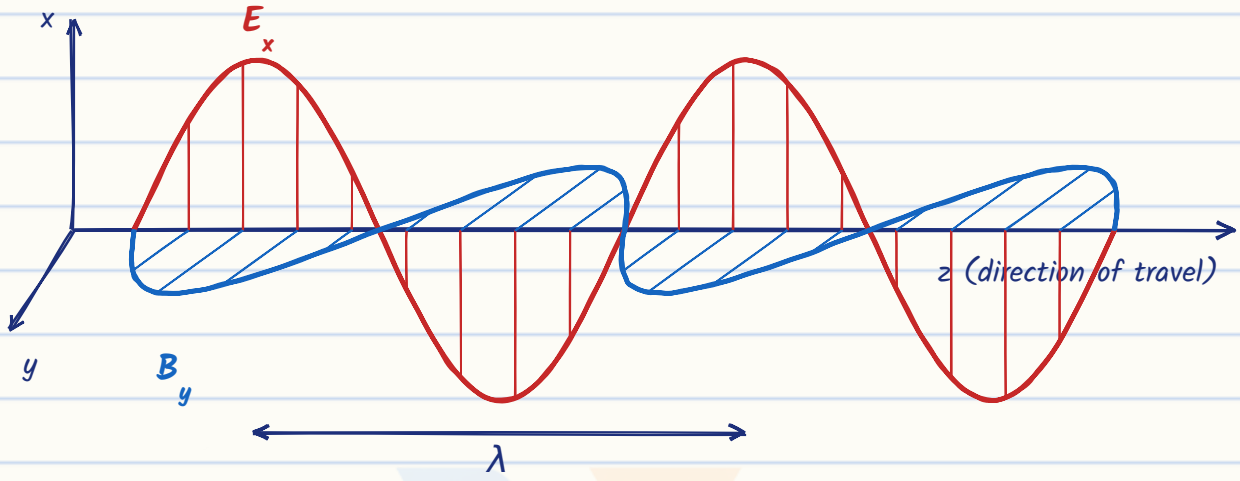
Source: **accelerated charges**. A charge at rest gives only E; a charge in uniform motion gives a steady B; only an accelerated charge radiates EM waves.



→ A charge oscillating with frequency ν produces an oscillating E, which produces an oscillating B, and so on — an EM wave of the **same frequency ν**.

→ Visible light needs $\nu \approx 10^{14}$–10^{15} Hz — too fast for circuits; it comes from **atoms and molecules**.

5. Nature of Electromagnetic Waves NCERT 8.3.2



$$E_x = E_0 \sin(kz - \omega t) \qquad B_y = B_0 \sin(kz - \omega t)$$

$k = 2\pi/\lambda$ (wave number), $\omega = 2\pi\nu$. E and B are perpendicular to each other and to the direction of travel, and they are **in phase**.

$$c = \omega/k = \nu\lambda = 1/\sqrt{(\mu_0\varepsilon_0)} = 3 \times 10^8 \text{ m/s}$$

$$E_0 / B_0 = c$$

⇒ Check: $1/\sqrt{(4\pi \times 10^{-7} \times 8.85 \times 10^{-12})} = 1/(3.33 \times 10^{-9}) \approx 3 \times 10^8$ m/s — the speed of light!

⇒ In a medium: $v = 1/\sqrt{(\mu\varepsilon)} = c/\sqrt{(\mu_r\varepsilon_r)} = c/n$

Properties of EM waves [S.L. Arora]

1. Produced by **accelerated charges**.
2. **Transverse**: $E \perp B \perp$ direction of propagation.
3. Need no medium — they are self-sustaining E and B oscillations.
4. All travel at the same speed c in vacuum. In a medium, frequency stays the same; speed and wavelength drop.
5. $E_0/B_0 = c$. They are not deflected by electric or magnetic fields (they are uncharged).
6. They carry **energy and momentum**, and exert pressure.

Example (NCERT): A plane EM wave of frequency 25 MHz travels in free space along x. At a point, E = 6.3 V/m along y. Find B there.

$B = E/c = 6.3/(3 \times 10^8) = \mathbf{2.1 \times 10^{-8}\ T}$, along z ($E \perp B \perp$ direction of travel)

Example (NCERT): $B_y = 2 \times 10^{-7} \sin(0.5 \times 10^3 x + 1.5 \times 10^{11} t)$ T. Find (a) λ and ν (b) the expression for E.

(a) $\lambda = 2\pi/k = 2\pi/500 = \mathbf{1.26\ cm}$; $\nu = \omega/2\pi = 1.5 \times 10^{11}/2\pi = \mathbf{23.9\ GHz}$

(b) $E_0 = cB_0 = 60$ V/m; $\mathbf{E_z = 60 \sin(0.5 \times 10^3 x + 1.5 \times 10^{11} t)\ V/m}$

6. Energy & Momentum of EM Waves NCERT 8.3.2 + [S.L. Arora]

→ Energy is shared equally between the electric and magnetic fields: $u_E = u_B$.

→ A wave carrying energy U also carries momentum **p = U/c**. When it falls on a surface, it exerts **radiation pressure**.

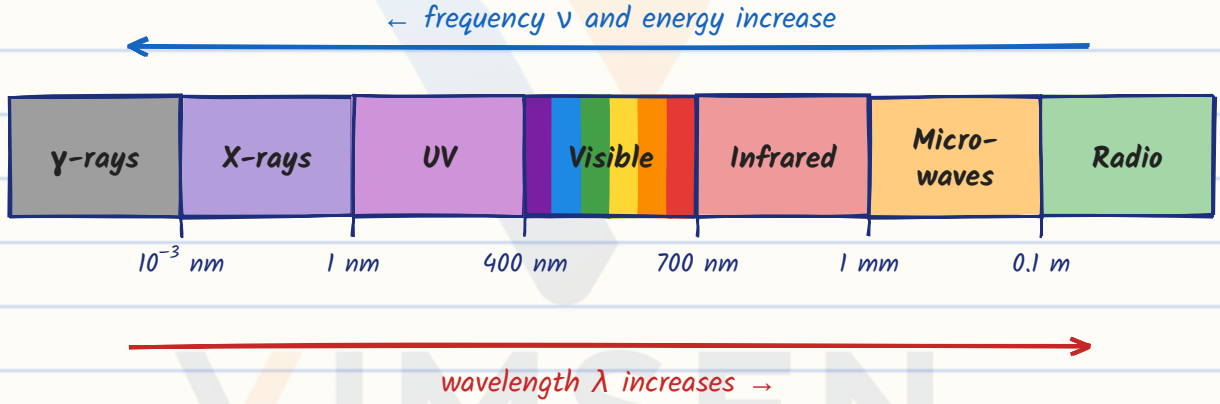
→ This is why we feel warm in sunlight, and why sunlight pushes comet tails away from the Sun.

$$u = \varepsilon_0 E^2 = B^2/\mu_0 \qquad u_{av} = \tfrac{1}{2}\varepsilon_0 E_0^2 \qquad I = u_{av}\, c$$

Momentum delivered to a surface: $p = U/c$ (complete absorption), $p = 2U/c$ (complete reflection).

7. Electromagnetic Spectrum NCERT 8.4

The orderly arrangement of EM waves by wavelength or frequency is the electromagnetic spectrum. All have the same speed c in vacuum; $c = \nu\lambda$.



Memory trick (low to high frequency): **R**aging **M**artians **I**nvaded **V**enus **U**sing **X**-ray **G**uns → Radio, Microwave, IR, Visible, UV, X-ray, Gamma.

Type	Wavelength	Production	Detection
Radio	> 0.1 m	accelerated electrons in aerials	receiver aerials
Microwave	0.1 m – 1 mm	klystron, magnetron, Gunn diode	point-contact diodes
Infrared	1 mm – 700 nm	vibration of atoms, molecules	thermopile, bolometer
Visible	700 – 400 nm	electrons in atoms (energy levels)	eye, photocell, film
UV	400 nm – 1 nm	inner-shell electrons, hot bodies	photocell, film
X-rays	1 nm – 10^{-3} nm	X-ray tubes, inner electrons	film, Geiger tube
Gamma	< 10^{-3} nm	radioactive decay of nucleus	film, ionisation chamber

8. Radio Waves & Microwaves NCERT 8.4.1–8.4.2

Radio waves (λ > 0.1 m)

→ Produced by **accelerated motion of charges** in conducting wires (aerials).

→ Uses: AM radio (530 kHz – 1710 kHz), FM radio (88 – 108 MHz), TV (54 – 890 MHz), mobile phones (UHF).

Microwaves (0.1 m – 1 mm)

→ Produced by special vacuum tubes: **klystrons, magnetrons, Gunn diodes.**

→ Uses: RADAR in aircraft navigation, speed guns, **microwave ovens**, satellite communication.

→ In an oven, the microwave frequency matches the natural frequency of water molecules. They absorb energy, vibrate and heat the food.

9. Infrared Waves & Visible Light NCERT 8.4.3–8.4.4

Infrared (1 mm – 700 nm) — "heat waves"

→ Produced by **hot bodies and molecules**.

→ Called heat waves because water molecules in most materials readily absorb IR, their thermal motion increases, and the body heats up.

→ Uses: physical therapy (IR lamps), TV **remote controls**, night-vision devices, IR photography for weather forecasting.

→ **Greenhouse effect:** the Earth re-emits IR, which is trapped by gases like CO_2, keeping the Earth warm.

Visible light (700 nm – 400 nm)

→ The only part of the spectrum our eyes can detect: **VIBGYOR**, violet (shortest λ) to red (longest λ).

→ Snakes can detect IR; insects such as bees can see some UV.

10. Ultraviolet, X-rays & Gamma Rays NCERT 8.4.5–8.4.7

Ultraviolet (400 nm – 1 nm)

→ Produced by special lamps and very hot bodies. The **Sun** is an important source.

→ Mostly absorbed by the ozone layer (≈ 40–50 km up). Overexposure causes skin cancer and sunburn.

→ Uses: **killing germs in water purifiers**, LASIK eye surgery. Welders wear special glass goggles to block UV from the welding arc.

X-rays (1 nm – 10^{-3} nm)

→ Produced by bombarding a metal target with high-energy electrons (X-ray tube).

→ Uses: medical diagnosis (bone photographs), treatment of some cancers (radiotherapy), studying crystal structure.

→ More harmful than UV: smaller λ → higher frequency → higher photon energy $E = h\nu$.

Gamma rays (< 10^{-3} nm)

→ Produced in **nuclear reactions** and by radioactive nuclei.

→ Uses: destroying cancer cells, sterilising medical equipment.

VIMSEN ACADEMY LEARN BEYOND LIMITS

11. Formula Sheet – Quick Revision

Displacement current	$i_d = \varepsilon_0 \, d\Phi_E/dt$
Ampere–Maxwell law	$\oint B \cdot dl = \mu_0(i_c + i_d)$
Wave equations	$E_x = E_0 \sin(kz - \omega t)$, $B_y = B_0 \sin(kz - \omega t)$
Speed in vacuum	$c = 1/\sqrt{(\mu_0\varepsilon_0)} = \nu\lambda = \omega/k$
Speed in medium	$v = 1/\sqrt{(\mu\varepsilon)} = c/\sqrt{(\mu_r\varepsilon_r)} = c/n$
Field ratio	$E_0/B_0 = c$ (in a medium = v)
Wave number	$k = 2\pi/\lambda$, $\omega = 2\pi\nu$
Energy density	$u_{av} = \frac{1}{2}\,\varepsilon_0 E_0^2$, $u_E = u_B$
Intensity	$I = u_{av}\, c$
Momentum	$p = U/c$ (absorbed), $2U/c$ (reflected)
Spectrum order (ν ↑)	Radio, Micro, IR, Visible, UV, X, γ

12. 20 Previous Year Questions CBSE Board

How to use: Questions 1–10 are MCQs (including one Assertion–Reason); 11–20 are subjective. Try each first, then read the solution. The Concept line tells you what the examiner is testing. Paper codes are given so you can check the original papers.

Part A — MCQs

PYQ 1 · CBSE 2025 (55/1/2) · MCQ

Going from microwaves to X-rays in vacuum, which is correct? (A) speed same, λ decreases, ν same (B) speed same, λ decreases, ν increases (C) speed increases, λ increases, ν decreases (D) speed same, λ increases, ν same

All EM waves travel at c in vacuum; X-rays have smaller λ, so $\nu = c/\lambda$ is larger ⇒ **(B)**

Concept: In vacuum only λ and ν change across the spectrum, always with $\nu\lambda = c$.

LEARN BEYOND LIMITS

PYQ 2 · CBSE 2025 (55/1/3) · MCQ

X-rays are more harmful to human beings than UV radiation because X-rays: (A) have lower frequency than UV (B) have smaller wavelength than UV (C) move faster than UV in air (D) are mechanical waves

Smaller λ → higher ν → higher photon energy ($E = hc/\lambda$) → deeper penetration and more damage ⇒ **(B)**

Concept: Energy of radiation grows as wavelength shrinks. Both are EM waves with the same speed.

PYQ 3 · CBSE 2024 (55/5/3) & 2026 (55/1/2) · MCQ

The electromagnetic waves used to purify water are: (A) infrared rays (B) ultraviolet rays (C) X-rays (D) gamma rays

(B) Ultraviolet rays — they kill bacteria and viruses.

Concept: Learn one use for every band. This question has appeared in both 2024 and 2026.

PYQ 4 · CBSE 2026 (55/1/3) · MCQ

Welders wear special glass goggles or face masks with glass windows to protect their eyes from: (A) infrared rays (B) ultraviolet rays (C) X-rays (D) microwaves

The welding arc emits a large amount of UV, which the special glass absorbs ⇒ **(B)**

Concept: UV sources: the Sun, welding arcs, special lamps. Ordinary and special glass absorb UV.

PYQ 5 · CBSE 2026 (55/1/1) · MCQ

Electromagnetic waves used as a diagnostic tool in medicine have a wavelength range: (A) 1 nm to 10^{-3} nm (B) 400 nm to 1 nm (C) 1 mm to 700 nm (D) 0.1 m to 1 mm

Diagnosis (bone photographs) uses X-rays: 1 nm – 10^{-3} nm ⇒ **(A)**

Concept: Match each band to its range: (B) UV, (C) IR, (D) microwaves. Learn the NCERT table.

PYQ 6 · CBSE 2026 (55/1/1, 55/1/2, 55/1/3) · MCQ

An EM wave passes from vacuum into a dielectric medium with relative permittivity 3/2 and relative permeability 8/3. Then its: (A) λ is doubled, ν unchanged (B) λ doubled, ν halved (C) λ halved, ν unchanged (D) λ and ν both unchanged

$n = \sqrt{(\mu_r \varepsilon_r)} = \sqrt{(8/3 \times 3/2)} = \sqrt{4} = 2 \Rightarrow v = c/2$

Frequency is set by the source (unchanged); $\lambda = v/\nu$ is halved $\Rightarrow$ **(C)**

Concept: Frequency never changes when a wave enters a new medium; speed and wavelength change together.

PYQ 7 · CBSE 2026 (55/3/2) · MCQ

The magnetic field of a plane EM wave in a medium is $B = 5 \times 10^{-8} \sin(3 \times 10^{10}\, t - 150\, x)$ T. The velocity of the wave is: (A) 2.0×10^8 m/s (B) 4.5×10^7 m/s (C) 3.5×10^7 m/s (D) 2.5×10^8 m/s

$\omega = 3 \times 10^{10}$ rad/s, $k = 150\ m^{-1}$; $v = \omega/k = 3 \times 10^{10}/150 =$ **2.0×10^8 m/s (A)**

Concept: Read ω (coefficient of t) and k (coefficient of x) from the equation; $v = \omega/k$.

PYQ 8 · CBSE 2026 (55/5/1, 55/5/2) · MCQ

The magnetic field of a plane EM wave in glass ($n = 1.5$) is $B_y = (2 \times 10^{-7}\ T)\ \sin(\alpha x + 1.5 \times 10^{11}\ t)$. The value of α is: (A) $0.5 \times 10^3\ m^{-1}$ (B) $6.0 \times 10^2\ m^{-1}$ (C) $7.5 \times 10^2\ m^{-1}$ (D) $1.5 \times 10^3\ m^{-1}$

$v = c/n = 3 \times 10^8/1.5 = 2 \times 10^8$ m/s; $\alpha = k = \omega/v = 1.5 \times 10^{11}/2 \times 10^8 =$ **$7.5 \times 10^2\ m^{-1}$ (C)**

Concept: In a medium use $v = c/n$, not c. The trap answer (A) uses c.

PYQ 9 · CBSE 2026 (55/4/1, 55/4/2) · MCQ

The ratio of the amplitude of the electric field to that of the magnetic field of an EM wave in glass ($n = 1.5$) is: (A) 3×10^8 m/s (B) 2×10^8 m/s (C) 3.3×10^{-9} m/s (D) 5×10^{-9} m/s

E_0/B_0 = speed of the wave in the medium = $c/n = 3 \times 10^8/1.5 =$ **2×10^8 m/s (B)**

Concept: $E_0/B_0 = c$ is only for vacuum. In general $E_0/B_0 = v$ (its unit is m/s).

LEARN BEYOND LIMITS

PYQ 10 · CBSE 2025 (55/7/2, 55/7/3) · Assertion–Reason

Assertion (A): EM waves do not require a medium for their propagation. **Reason (R):** EM waves are transverse waves.

Both are true, but transverse nature is **not** why no medium is needed (waves on a string are also transverse, yet they need the string) ⇒ **(B)**

Concept: EM waves need no medium because changing E and B fields regenerate each other — they are self-sustaining.

Part B — Subjective

PYQ 11 · CBSE 2026 (55/5/1)

(i) Define displacement current. (ii) Using the charging of a capacitor, show that $i_d = \varepsilon_0 \, d\Phi_E/dt$. What is i_d for a conductor across which a constant voltage is applied?

(i) Current due to a changing electric field (flux) — see Topic 2.

(ii) $E = q/\varepsilon_0 A \Rightarrow \Phi_E = q/\varepsilon_0 \Rightarrow \varepsilon_0 \, d\Phi_E/dt = dq/dt = i_d$. Constant voltage → E constant → $i_d = 0$

Concept: Displacement current needs a **changing** E. Steady fields give none.

PYQ 12 · CBSE 2025 (55/1/2, 55/1/3) · Q25(a)

A parallel plate capacitor is charged by an AC source. Show that the sum of conduction current I_c and displacement current I_d has the same value at all points of the circuit.

In the wires: $I_d = 0$, total = I_c. Between the plates: $I_c = 0$, total = $I_d = \varepsilon_0 A \, dE/dt = dq/dt = I_c$

So $I_c + I_d$ is the same everywhere — the total current is continuous.

Concept: Displacement current "fills the gap" so the current never breaks.

PYQ 13 · CBSE 2025 (55/1/2, 55/1/3) · Q25(b)

In the above case, is Kirchhoff's first rule (junction rule) valid at each plate of the capacitor? Explain.

Yes, if displacement current is included. Conduction current entering a plate = displacement current leaving it across the gap.

Concept: Without i_d, charge would seem to pile up and the junction rule would fail. Maxwell's correction fixes it.

PYQ 14 · CBSE 2026 (55/5/2)

(i) Differentiate between conduction current and displacement current. (ii) A capacitor is connected across a source giving a time-dependent current. Explain how the total current at an instant is the sum of the conduction and displacement currents.

(i) See the comparison table in Topic 2: flow of charge vs changing E field; conductor vs gap.

(ii) $i = i_c + i_d$. In the wire only i_c, in the gap only i_d, with $i_c = i_d$ at every instant → the total is the same everywhere.

Concept: Write the Ampere–Maxwell law: the source term is $i_c + i_d$.

PYQ 15 · CBSE 2026 (55/3/2)

(a) Depict the variation of E and B with the direction of propagation of an EM wave and write two characteristics. (b) Show that $1/\sqrt{(\varepsilon_0\mu_0)}$ gives the velocity of an EM wave in free space.

(a) Draw the Topic 5 diagram. Characteristics: $E \perp B \perp$ direction of travel (transverse); E and B in phase with $E_0/B_0 = c$.

(b) $1/\sqrt{(4\pi \times 10^{-7} \times 8.854 \times 10^{-12})} = 1/(3.336 \times 10^{-9}) = 3 \times 10^8$ m/s = c. Dimensions of $1/\sqrt{(\mu_0\varepsilon_0)} = [L\ T^{-1}]$ (speed).

Concept: Maxwell's prediction: the EM wave speed equals the measured speed of light, so light is an EM wave.

PYQ 16 · CBSE 2025 (55/7/2)

(a) How are electromagnetic waves produced? (b) Write the wavelength range and one use of (i) microwaves (ii) ultraviolet waves.

(a) By **accelerated (oscillating) charges**: an oscillating charge makes oscillating E and B fields of the same frequency.

(b) (i) Microwaves: **0.1 m – 1 mm**, RADAR / microwave oven. (ii) UV: **400 nm – 1 nm**, killing germs in water purifiers.

Concept: Charges at rest or in uniform motion do not radiate — acceleration is essential.

PYQ 17 · CBSE 2025 (55/7/3)

Name the EM radiations and write their frequency range: (a) used to take photographs of bones (b) produced by hot bodies (c) used in television communication.

(a) **X-rays**: about $3 \times 10^{17} - 3 \times 10^{20}$ Hz (b) **Infrared**: about $3 \times 10^{11} - 4.3 \times 10^{14}$ Hz

(c) **Radio waves (VHF/UHF)**: 54 MHz – 890 MHz

Concept: Convert the NCERT wavelength ranges with $\nu = c/\lambda$ when frequency is asked.

PYQ 18 · CBSE 2026 (55/4/1)

(i) What are infrared waves? (ii) Why are they called "heat waves"? (iii) Give any two uses of infrared waves.

(i) EM waves of wavelength 1 mm – 700 nm, produced by hot bodies and molecules.

(ii) Water molecules in most materials readily absorb IR, so their thermal motion — and the temperature — increases.

(iii) TV remote controls; physical therapy (IR lamps); night vision; weather forecasting.

Concept: "Heat waves" because they **raise temperature** on absorption, not because they are hot.

PYQ 19 · CBSE 2026 (55/4/2)

(i) What are microwaves? (ii) How are they produced? (iii) Give two uses of microwaves.

(i) EM waves of wavelength 0.1 m – 1 mm (short-wavelength radio waves).

(ii) By special vacuum tubes — klystrons, magnetrons and Gunn diodes. (iii) RADAR in aircraft navigation; microwave ovens.

Concept: Microwave ovens work because the microwave frequency matches the natural frequency of water molecules.

PYQ 20 · CBSE 2024 (55/5/3)

(a) Name the parts of the EM spectrum that (i) are called "heat waves" (ii) are absorbed by the ozone layer. (b) Briefly describe one method each of producing and detecting (i) infrared (ii) ultraviolet radiation.

(a) (i) **Infrared** (ii) **Ultraviolet**

(b) IR: produced by hot bodies (vibrating molecules); detected by thermopiles or bolometers.

UV: produced by the Sun or special lamps (very hot bodies); detected by photocells or photographic film.

Concept: The production/detection columns of the NCERT spectrum table are frequently asked — learn them row by row.