# Electromagnetic Waves

Class 12 · Physics · Quick Revision · **chapternotes.in**

NEET: 1-2 Qs (~4 marks) | Boards: 3-4 marks

Scan: practise free

> Maxwell's missing term (displacement current) made a changing E field act like a current, predicting self-sustaining E-B waves that travel at light speed and span one big spectrum.

## 1. Displacement Current & Ampere-Maxwell Law

*A changing electric field acts like a current and produces a magnetic field.*

**displacement current $I_d = \varepsilon_0 \frac{d\Phi_E}{dt}$**
$\Phi_E$ = electric flux

**$\oint B \cdot dl = \mu_0(I_c + I_d)$**
Ampere-Maxwell law

**$I_d = \varepsilon_0 \frac{d\Phi_E}{dt} = I_c$**
equal across capacitor gap

MUST KNOW Ampere's law failed for a charging capacitor (current in wire, none between plates); I_d fixes it so B is continuous.

MUST KNOW I_d is NOT flow of charge - it is due to a time-varying electric flux; it exists wherever E changes with time.

- The symmetry (changing E makes B, changing B makes E) is what predicts EM waves.

## 2. Nature of EM Waves (E ⊥ B ⊥ c)

*Self-sustaining transverse waves of mutually perpendicular E and B, in phase.*

**$E_y = E_0 \sin(kx - \omega t)$**
E along y

**$B_z = B_0 \sin(kx - \omega t)$**
B along z, in phase with E

**wave travels along E × B**
Poynting direction

MUST KNOW Transverse: E ⊥ B ⊥ direction of travel; E and B oscillate in phase (peak and zero together).

MUST KNOW Carry energy and momentum but NO charge, so they are not deflected by electric or magnetic fields.

- Produced only by accelerating (oscillating) charges; need NO medium - travel through vacuum.

## 3. Speed, Energy & Momentum

*Speed depends only on $\mu_0$, $\varepsilon_0$; energy is shared equally between E and B.*

**$c = 1/\sqrt{(\mu_0\varepsilon_0)} = 3\times10^8$ m/s**
vacuum speed

**$v = 1/\sqrt{(\mu\varepsilon)} = c/n$**
in a medium, v < c

**$c = E_0/B_0$**
also E = cB every instant

**$u_E = \frac{1}{2}\varepsilon_0 E^2$, $u_B = B^2/2\mu_0$, $u_E = u_B$ (energy shared equally)**
average densities

**$I = \frac{1}{2}\varepsilon_0 c E_0^2$, $p = U/c$**
intensity; momentum for energy U

MUST KNOW Energy is split 50-50 between E and B; use rms values for averages ($E_{rms} = E_0/\sqrt{2}$), hence the ½.

MUST KNOW Radiation pressure: full reflection delivers double the momentum (p = 2U/c) versus full absorption (p = U/c).

- In a medium frequency stays fixed; speed drops to c/n and wavelength shrinks.

## 4. EM Spectrum: Order & Uses

*All EM waves share speed c; they differ only in frequency/wavelength.*

**$c = f\lambda$**
same c, so f up ⇒ λ down

**$E = hf$**
higher f ⇒ higher photon energy

MUST KNOW Increasing frequency (decreasing λ): Radio < Microwave < IR < Visible < UV < X-ray < Gamma.

MUST KNOW Uses: Radio (TV/mobile), Microwave (radar, ovens-heat water), IR (heating, remotes, thermography), UV (sterilise), X-ray (imaging), Gamma (cancer therapy).

- Within visible (VIBGYOR): Violet highest f, Red lowest f (longest λ).

## 5. Key Facts & Sources of Each Band

*Know the source and one signature fact for each band - pure recall marks.*

**λ (visible) ≈ 400-700 nm**
thin slice eyes detect

**λ (X-ray) ≈ 0.1-100 Å**
~ interatomic spacing

MUST KNOW Sources: Radio (oscillating circuits/antennas), Microwave (klystron/magnetron), IR (hot bodies, molecular vibration), Visible/UV (atoms, Sun), X-ray (fast electrons hit metal), Gamma (nuclei/radioactive decay).

MUST KNOW Ozone absorbs UV (not IR); IR drives the greenhouse effect; X-rays probe crystal/solid structure (diffraction).

- β-rays are charged electrons, NOT EM waves; heat/IR, X-rays and gamma ARE EM waves.

## EM Spectrum (increasing frequency →)

| Wave | Wavelength | Source | Use |
|---|---|---|---|
| Radio | > 0.1 m | Oscillating circuits/antennas | TV, radio, mobile |
| Microwave | 0.1 m - 1 mm | Klystron/magnetron | Radar, ovens |
| Infrared | 1 mm - 700 nm | Hot bodies, vibrations | Heating, remotes, thermography |
| Visible | 700 - 400 nm | Atoms (Sun, lamps) | Sight |
| Ultraviolet | 400 - 1 nm | Sun, special lamps | Sterilise (ozone absorbs) |
| X-ray | 1 nm - 1 pm | Fast electrons on metal | Medical imaging |
| Gamma | < 1 pm | Nuclei / radioactive decay | Cancer therapy |

## Energy & Momentum Quick Facts

| Quantity | Relation |
|---|---|
| Energy density | $u_E = u_B$ (shared equally) |
| Intensity | $I = \frac{1}{2}\varepsilon_0 c E_0^2$ |
| Momentum (absorbed) | $p = U/c$ |
| Momentum (reflected) | $p = 2U/c$ (doubles) |

**Mnemonic - EM spectrum by increasing frequency: Radio, Microwave, Infrared, Visible, Ultraviolet, X-ray, Gamma**
Roman Men Invented Very Unusual X-ray Guns

### Common traps

- Displacement current is NOT moving charge - it is $\varepsilon_0 d\Phi_E/dt$, a changing electric flux. It exists anywhere E changes with time, not just in capacitors.
- E and B in a vacuum EM wave are in PHASE, not 90° out of phase. They are mutually perpendicular but peak together.
- Speed is $c = 1/\sqrt{(\mu_0\varepsilon_0)}$, the reciprocal - not $\sqrt{(\mu_0\varepsilon_0)}$. In glass the wave SLOWS to c/n; it never speeds up.
- Order of the spectrum: frequency rises and wavelength falls from Radio to Gamma. Don't mix IR (heat, longer λ) with UV (sunburn, shorter λ); ozone absorbs UV, not IR.

**Most asked in NEET »** Displacement current $I_d = \varepsilon_0 d\Phi_E/dt = C\,dV/dt$ · Direction: wave along E × B · $c = 1/\sqrt{(\mu_0\varepsilon_0)}$, $E_0 = cB_0$ · Energy shared equally (uE = uB, 1:1) · Radiation pressure: reflection ⇒ 2E/c · Spectrum order & λ ranking · Ozone absorbs UV / greenhouse = IR