Collegedunia NCERT Formula Sheet

The Ultimate Formula Reference for Class 12 Physics

Chapter 8: Electromagnetic Waves

Constant / Unit	Value
Speed of light in vacuum, c	3×10^8 m/s
ϵ_0	8.854×10^{-12} C^2/(N·m^2)
μ_0	$4\pi \times 10^{-7}$ T·m/A
$1/\sqrt{\mu_0 \epsilon_0}$	$c \approx 3 \times 10^8$ m/s
Visible wavelength range	400–700 nm

1 Displacement Current

Maxwell's missing piece: a changing electric field produces a magnetic field, just as a changing magnetic field produces an electric field (NCERT 8.2).

Why displacement current?

Ampere's law in its old form ($\oint \vec{B} \cdot d\vec{l} = \mu_0 I$) fails for a circuit containing a charging capacitor: the same Amperian loop encloses a current on one side and zero on the other. Maxwell fixed it by adding a **displacement current** term — a changing electric flux acts like a current.

Displacement current

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

where $\Phi_E = \int \vec{E} \cdot d\vec{A}$ = electric flux.

Not a flow of charge — a **changing electric field** that produces a magnetic field exactly as a real current would. Its existence ensures continuity of $\vec{B}$ across a charging capacitor.

Modified Ampere–Maxwell law

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 (I_c + I_d) = \mu_0 I_c + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$$

I_c = conduction current; I_d = displacement current. The Ampere–Maxwell law is one of the four **Maxwell equations**.

2 Maxwell's Equations & EM Wave Propagation

The four Maxwell equations together predict that $\vec{E}$ and $\vec{B}$ fields can sustain each other and propagate as a wave at the speed of light (NCERT 8.3).

Maxwell's equations (free space)

Gauss for E: $\oint \vec{E} \cdot d\vec{A} = q/\epsilon_0$.
Gauss for B: $\oint \vec{B} \cdot d\vec{A} = 0$ (no monopoles).
Faraday: $\oint \vec{E} \cdot d\vec{l} = -d\Phi_B/dt$.
Ampere–Maxwell: $\oint \vec{B} \cdot d\vec{l} = \mu_0 I + \mu_0\epsilon_0\, d\Phi_E/dt$.

Speed of EM waves

Vacuum: $c = \frac{1}{\sqrt{\mu_0\epsilon_0}} \approx 3 \times 10^8$ m/s

In a medium: $v = \frac{1}{\sqrt{\mu\epsilon}} = \frac{c}{n}$

where $n = \sqrt{\mu_r\epsilon_r}$ = refractive index.

Light is an electromagnetic wave — this connection is the deepest payoff of Maxwell's theory. In a denser medium, $v < c$.

Relation between E_0 and B_0

$\frac{E_0}{B_0} = c$

E_0, B_0, and $\hat{c}$ form a right-handed triad.

$\vec{E}$ and $\vec{B}$ are mutually perpendicular and both perpendicular to the direction of propagation. They oscillate **in phase** (peak together).

Properties of EM waves

(i) **Transverse**: $\vec{E}$, $\vec{B}$ both perpendicular to $\hat{c}$.
(ii) Travel at speed c in vacuum, regardless of frequency.
(iii) Carry both **energy** and **momentum** — can exert pressure on absorbing surfaces (radiation pressure).
(iv) Do **not** require a medium.
(v) Obey reflection, refraction, interference, diffraction, polarisation.

3 Energy & Intensity

EM waves carry energy in both their electric and magnetic field components — equally divided. Average intensity is the time-averaged power per unit area (NCERT 8.4).

Energy density

$u_E = \frac{1}{2}\epsilon_0 E^2 \quad (u_B = B^2/2\mu_0)$

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

$u_E = u_B$ at every instant in an EM wave: the wave's energy is split equally between the two fields.

Intensity (time-averaged)

$I = \langle u \rangle c = \frac{1}{2}\epsilon_0 E_0^2 c = \frac{E_0 B_0}{2\mu_0}$

$I = \frac{P}{A}$ (W/m^2)

Intensity drops as $1/r^2$ for a point source. The factor of $1/2$ comes from time-averaging $\sin^2$ over a cycle.

Momentum & radiation pressure

Momentum: $p = \frac{U}{c}$

Pressure on absorbing surface: $P_{\text{rad}} = \frac{I}{c}$

Pressure on reflecting surface: $P_{\text{rad}} = \frac{2I}{c}$

Tiny but real — comet tails always point away from the Sun because of solar radiation pressure on the dust.

4 The EM Spectrum

A single phenomenon (EM waves) covers a vast range of frequencies, from radio (low) to gamma (high). Behaviour and applications differ by frequency band (NCERT 8.5).

Spectrum bands (low to high frequency)

Radio waves: $\sim$ kHz–GHz; AM/FM radio, TV.
Microwaves: GHz; radar, microwave ovens, mobile phones.
Infrared: $\sim 10^{12}$ Hz; heat, thermal imaging, remote controls.
Visible: 4×10^{14} to 7.5×10^{14} Hz; what eyes detect.
Ultraviolet: tans skin, sterilises water; absorbed by ozone.
X-rays: medical imaging, security scans; ionising.
Gamma rays: nuclear processes; deeply penetrating, highly ionising.

Wavelength–frequency relation

$c = f\lambda$

Photon energy: $E = hf = \dfrac{hc}{\lambda}$

As f rises, λ falls and photon energy rises. Same relation across all bands of the spectrum.

Spectrum order: "Raging Martians Invaded Venus Using X-ray Guns"

Radio, **M**icrowave, **I**nfrared, **V**isible, **U**ltraviolet, **X**-ray, **G**amma — low frequency (long wavelength) to high frequency (short wavelength). Photon energy increases left to right.

JEE/NEET Extension: Visible spectrum order

VIBGYOR: Violet (shortest λ, ~ 400 nm), Indigo, Blue, Green, Yellow, Orange, Red (longest λ, ~ 700 nm). Frequency **decreases** left to right; wavelength **increases**.

Wave vs particle picture

EM radiation behaves as a **wave** (interference, diffraction) and as **particles** (photons — in the photoelectric effect, Compton scattering). Don't try to use one picture exclusively. The wavelength tells you when wave behaviour matters; the photon energy tells you when particle behaviour matters.

Quick Reference — Electromagnetic Waves

Quantity / Concept	Expression	Notes
Displacement current	$\epsilon_0 \, d\Phi_E/dt$	Closes Ampere's law
Speed in vacuum	$1/\sqrt{\mu_0\epsilon_0}$	$\approx 3 \times 10^8$ m/s
Speed in medium	c/n	$n = \sqrt{\mu_r\epsilon_r}$
E_0/B_0 ratio	c	In phase, $\perp$ to each other
Frequency relation	$c = f\lambda$	All EM waves
Photon energy	$hf = hc/\lambda$	Particle picture
Energy density (E)	$\frac{1}{2}\epsilon_0 E^2$	Per m^3
Energy density (B)	$\frac{B^2}{2\mu_0}$	Equals u_E
Intensity	$\frac{1}{2}\epsilon_0 E_0^2 c$	Time-averaged
Momentum (photon)	U/c	Carries momentum
Pressure (absorber)	I/c	Radiation pressure
Pressure (reflector)	$2I/c$	Twice an absorber