

Class 12 Physics Derivations, Chapter-wise

All examinable derivations · marked with CBSE board years 2022–2026 · CBSE syllabus 2026–27 · NCERT textbook (Reprint 2026–27)

How to use this sheet. Derivations are grouped by NCERT chapter and, inside each chapter, ordered by how often CBSE asked them in the 2022–2026 board papers. The badge on each one shows the year and marks it carried. Steps follow the NCERT textbook (Reprint 2026–27), so you can write them the way the book does. Diagrams are not to scale. **Asked** = asked as a derivation in the board exam. **In NCERT** = derived in the book but not asked in 2022–2026. **Not in NCERT** = asked in the board exam but not worked out in the book.

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|--|--|
| 1. Ch 1. Electric Charges and Fields (6 derivations) | 8. Ch 8. Electromagnetic Waves (1 derivation) |
| 2. Ch 2. Electrostatic Potential and Capacitance (8 derivations) | 9. Ch 9. Ray Optics and Optical Instruments (14 derivations) |
| 3. Ch 3. Current Electricity (7 derivations) | 10. Ch 10. Wave Optics (4 derivations) |
| 4. Ch 4. Moving Charges and Magnetism (7 derivations) | 11. Ch 11. Dual Nature of Radiation and Matter (3 derivations) |
| 5. Ch 5. Magnetism and Matter (no derivations) | 12. Ch 12. Atoms (4 derivations) |
| 6. Ch 6. Electromagnetic Induction (7 derivations) | 13. Ch 13. Nuclei (2 derivations) |
| 7. Ch 7. Alternating Current (5 derivations) | 14. Ch 14. Semiconductor Electronics (no derivations) |

Most-asked derivations, CBSE 2022–2026

#	Derivation	Chapter	Asked in (marks)
6.1	Mutual inductance: two co-axial solenoids, and two concentric coplanar loops	Electromagnetic Induction	2023 (3m) · 2024 (5m) · 2025 (3m) · 2026 (3m)
4.1	Biot–Savart law: field on the axis of a circular current loop, and at its centre	Moving Charges and Magnetism	2023 (5m) · 2025 (3m) · 2026 (3m)
6.2	Self-inductance of a long solenoid: $L = \mu_0 n^2 Al$	Electromagnetic Induction	2023 (3m) · 2025 (3m) · 2026 (5m)
7.1	Series LCR circuit: impedance and phase angle from the phasor diagram	Alternating Current	2023 (3m) · 2024 (5m) · 2026 (5m)
9.1	Astronomical (refracting) telescope: magnifying power in normal adjustment	Ray Optics and Optical Instruments	2022 (3m) · 2023 (5m) · 2026 (5m)
9.2	Compound microscope: magnifying power (near point and infinity)	Ray Optics and Optical Instruments	2024 (5m) · 2025 (5m) · 2026 (3m)
10.1	Resultant intensity of two coherent waves: $I = 4I_0 \cos^2(\phi/2)$	Wave Optics	2024 (2m, 5m) · 2025 (5m) · 2026 (2m)
13.1	Nuclear density is the same for all nuclei	Nuclei	2023 (3m, 2m) · 2024 (3m) · 2026 (3m, 2m)
1.1	Gauss's law: field of a uniformly charged infinite plane sheet	Electric Charges and Fields	2023 (5m, 2m) · 2026 (3m)
1.2	Electric field of a dipole on its equatorial plane	Electric Charges and Fields	2025 (5m) · 2026 (5m)
2.1	Electric potential due to a dipole at a far point	Electrostatic Potential and Capacitance	2024 (5m) · 2025 (5m)
3.1	Drift velocity $\mathbf{v}_d = -\frac{e\mathbf{E}}{m}\tau$ and current $I = neAv_d$	Current Electricity	2025 (3m) · 2026 (2m, 3m, 5m)
3.2	Ohm's law from drift: $\mathbf{j} = \frac{ne^2\tau}{m}\mathbf{E}$, resistivity $\rho = \frac{m}{ne^2\tau}$	Current Electricity	2024 (3m, 2m) · 2025 (3m)
4.2	Force between two long parallel current-carrying conductors; definition of the ampere	Moving Charges and Magnetism	2024 (3m) · 2026 (3m)



4.3	Torque on a rectangular current loop in a uniform magnetic field: $\tau = \mathbf{m} \times \mathbf{B}$	Moving Charges and Magnetism	2024 (3m) · 2026 (5m)
4.4	Magnetic moment of an orbiting electron: $\mu_e = -\frac{e}{2m_e} \mathbf{L}$	Moving Charges and Magnetism	2024 (3m) · 2025 (3m) · Not in NCERT
6.3	Energy stored in an inductor $\frac{1}{2}LI^2$, and magnetic energy density $\frac{B^2}{2\mu_0}$	Electromagnetic Induction	2025 (5m, 3m) · 2026 (3m)
6.5	Motional emf $\varepsilon = Blv$, and the energy argument (current, force, power)	Electromagnetic Induction	2023 (3m) · 2025 (5m) · Energy part not in NCERT
8.1	Displacement current $i_d = \varepsilon_0 \frac{d\Phi_E}{dt}$ and the Ampere–Maxwell law	Electromagnetic Waves	2025 (3m) · 2026 (3m)
9.3	Mirror formula $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$ and magnification $m = -\frac{v}{u}$	Ray Optics and Optical Instruments	2023 (5m) · 2025 (3m)
12.1	Bohr model: radius of the n th orbit, $r_n \propto n^2$	Atoms	2024 (3m) · 2025 (3m)
12.2	Total energy of the electron, $E_n = -\frac{13.6}{n^2}$ eV	Atoms	2025 (3m) · 2026 (3m)
1.3	Gauss's law: field of a uniformly charged thin spherical shell (outside and inside)	Electric Charges and Fields	2024 (5m)
1.4	Gauss's law: field of an infinitely long, uniformly charged straight wire	Electric Charges and Fields	2023 (2m)
2.2	Capacitance of a parallel plate capacitor (air between the plates)	Electrostatic Potential and Capacitance	2026 (5m)
2.3	Parallel plate capacitor with a dielectric: $C = \frac{K\varepsilon_0 A}{d}$	Electrostatic Potential and Capacitance	2024 (5m)
2.4	Potential energy of a dipole in a uniform electric field: $U = -\mathbf{p} \cdot \mathbf{E}$	Electrostatic Potential and Capacitance	2024 (5m)
2.5	Potential energy of a system of two and three point charges	Electrostatic Potential and Capacitance	2023 (2m)
3.3	Balance condition of a Wheatstone bridge: $\frac{R_2}{R_1} = \frac{R_4}{R_3}$	Current Electricity	2026 (3m, 5m)
3.4	Two cells in parallel: equivalent emf and internal resistance	Current Electricity	2025 (3m)
4.5	Ampere's circuital law: field of an infinitely long straight wire	Moving Charges and Magnetism	2025 (3m)
4.6	Charged particle in a uniform magnetic field: radius, frequency and helical path	Moving Charges and Magnetism	2024 (5m)
6.4	EMF induced in a rod rotating about one end: $\varepsilon = \frac{1}{2}B\omega L^2$	Electromagnetic Induction	2025 (3m)
6.6	EMF of a coil rotating in a uniform field (AC generator): $\varepsilon = NBA\omega \sin \omega t$	Electromagnetic Induction	2024 (5m)
6.7	Induced charge depends only on the change in flux: $Q = \frac{\Delta\Phi}{R}$	Electromagnetic Induction	2024 (3m) · Not in NCERT
7.2	AC voltage across a capacitor: current leads by $\pi/2$, $X_C = \frac{1}{\omega C}$	Alternating Current	2023 (3m)
7.3	Average power in a series LCR circuit $P = VI \cos \phi$, and resonant frequency	Alternating Current	2024 (3m)
7.4	AC voltage across an inductor: current lags by $\pi/2$, $X_L = \omega L$, no average power	Alternating Current	2024 (3m)



9.4	Refraction through a prism: $r_1 + r_2 = A$ and $\delta = i + e - A$	Ray Optics and Optical Instruments	2024 (5m)
9.5	Refractive index of a prism from minimum deviation	Ray Optics and Optical Instruments	2026 (5m)
9.6	Refraction at a convex spherical surface: $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$	Ray Optics and Optical Instruments	2026 (5m)
9.7	Lens maker's formula: $\frac{1}{f} = (n_{21} - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$	Ray Optics and Optical Instruments	2026 (5m)
9.9	Two thin lenses in contact: $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$	Ray Optics and Optical Instruments	2026 (2m)
9.10	Lateral shift through a parallel-sided glass slab	Ray Optics and Optical Instruments	2025 (3m) · Not in NCERT
10.2	Conditions for constructive and destructive interference in terms of path difference	Wave Optics	2025 (5m)
10.3	Huygens' principle: proof of Snell's law of refraction	Wave Optics	2025 (5m)
11.1	de Broglie wavelength of a charged particle accelerated through a potential difference	Dual Nature of Radiation and Matter	2026 (3m)
11.2	The de Broglie wavelength of a photon equals the wavelength of the radiation	Dual Nature of Radiation and Matter	2026 (3m)
12.3	Time period of the electron in the n th orbit, $T \propto n^3$	Atoms	2025 (2m) · Not in NCERT
12.4	Distance of closest approach of an alpha particle	Atoms	2025 (2m)
13.2	Energy equivalent of one atomic mass unit: $1 \text{ u} = 931.5 \text{ MeV}$	Nuclei	2026 (3m)

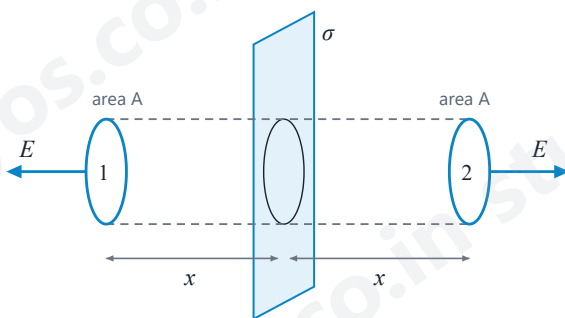
1 Electric Charges and Fields

1.1 Gauss's law: field of a uniformly charged infinite plane sheet

Asked 2023 (5m, 2m) · 2026 (3m)

NCERT §1.14.2, Eq. 1.33.





Gaussian surface: a cylinder (or box) of end area A cutting the sheet. NCERT uses a rectangular box; either works.

1. By symmetry, $\mathbf{E}$ is perpendicular to the sheet, the same on both sides, and does not depend on y or z .
2. Only the two end faces 1 and 2 contribute to the flux. On the curved (side) surface $\mathbf{E}$ is parallel to the surface, so its flux is zero.
3. On faces 1 and 2, $\mathbf{E}$ is along the outward normal, so each contributes EA :

$$\Phi = EA + EA = 2EA$$

4. Charge enclosed $= \sigma A$. Gauss's law, $\Phi = q_{\text{enc}}/\epsilon_0$:

$$2EA = \frac{\sigma A}{\epsilon_0}$$

$$E = \frac{\sigma}{2\epsilon_0}, \quad \mathbf{E} = \frac{\sigma}{2\epsilon_0} \hat{n}$$

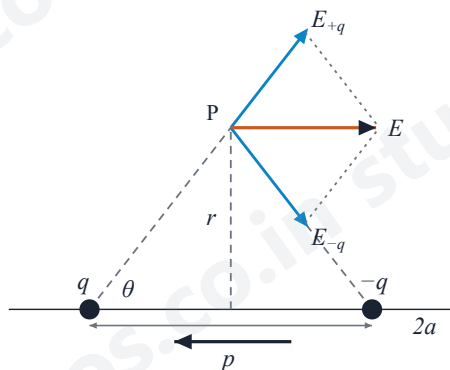
$\hat{n}$ points away from the sheet (towards it if $\sigma < 0$). The field does not depend on the distance x from the sheet.

Common mistake: writing σ/ϵ_0 . The thin sheet has field lines leaving from both faces, so the flux is $2EA$, not EA . (σ/ϵ_0 is the field just outside a charged conductor.)

1.2 Electric field of a dipole on its equatorial plane

Asked 2025 (5m) · 2026 (5m)

2025 asked it as "+q and -q at (a, 0) and (-a, 0), field at (0, y)", which is the same derivation. NCERT §1.10.1, Eqs. 1.16–1.18.



P is at distance r from the centre on the perpendicular bisector. $\mathbf{p}$ points from $-q$ to q .

1. P is the same distance $\sqrt{r^2 + a^2}$ from both charges, so the two fields are equal in magnitude:

$$E_{+q} = E_{-q} = \frac{q}{4\pi\epsilon_0} \frac{1}{r^2 + a^2}$$

2. Their components normal to the dipole axis cancel. The components along the axis add, and point opposite to $\hat{\mathbf{p}}$:

$$\mathbf{E} = -(E_{+q} + E_{-q}) \cos \theta \hat{\mathbf{p}}$$

3. From the figure, $\cos \theta = \frac{a}{\sqrt{r^2 + a^2}}$, so

$$\mathbf{E} = -\frac{2qa}{4\pi\epsilon_0(r^2 + a^2)^{3/2}} \hat{\mathbf{p}}$$

4. With $\mathbf{p} = q \times 2a \hat{\mathbf{p}}$, and for a far point $r \gg a$:

$$\mathbf{E} = -\frac{\mathbf{p}}{4\pi\epsilon_0(r^2 + a^2)^{3/2}} \xrightarrow{r \gg a} \mathbf{E} = -\frac{\mathbf{p}}{4\pi\epsilon_0 r^3}$$

Common mistake: dropping the minus sign. On the equatorial plane the field is opposite to $\mathbf{p}$; on the axis it is along $\mathbf{p}$ (derivation 1.5).

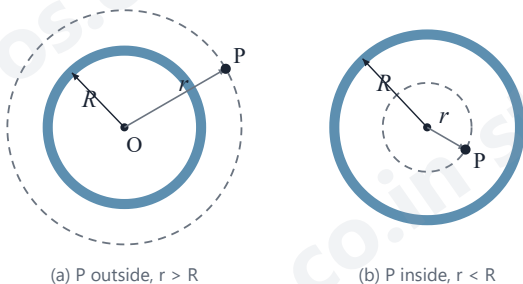
1.3 Gauss's law: field of a uniformly charged thin spherical shell (outside and inside)

Asked 2024 (5m)

Asked for a conducting shell of charge Q ; the charge sits on the surface, so it is the same derivation. NCERT §1.14.3, Eqs. 1.34–



1.35.

(a) P outside, $r > R$ (b) P inside, $r < R$

The shell (thick) has radius R and surface charge density σ . The dashed sphere of radius r through P is the Gaussian surface.

(i) Outside the shell, $r > R$.

- By spherical symmetry, $\mathbf{E}$ is radial and has the same magnitude everywhere on the Gaussian sphere. Flux = $E \times 4\pi r^2$.
- Charge enclosed is the whole shell: $q = \sigma \times 4\pi R^2$.
Gauss's law:

$$E \times 4\pi r^2 = \frac{\sigma}{\epsilon_0} 4\pi R^2 \Rightarrow E = \frac{\sigma R^2}{\epsilon_0 r^2} = \frac{q}{4\pi\epsilon_0 r^2}$$

(ii) Inside the shell, $r < R$. The flux is again $E \times 4\pi r^2$, but the Gaussian sphere encloses no charge: $E \times 4\pi r^2 = 0$.

$$\mathbf{E} = \frac{q}{4\pi\epsilon_0 r^2} \hat{\mathbf{r}} \quad (r > R), \quad E = 0 \quad (r < R)$$

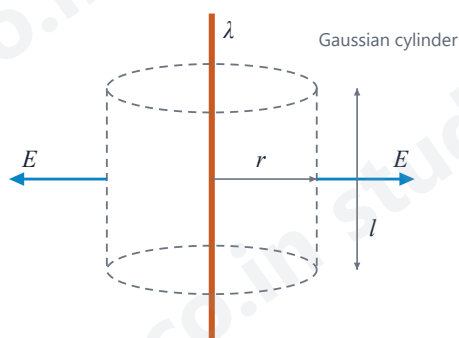
Outside, the shell acts as if all its charge were at the centre. The zero field inside follows from the $1/r^2$ form of Coulomb's law.

Common mistake: using R instead of r in the flux. The Gaussian sphere passes through P, so its area is $4\pi r^2$.

1.4 Gauss's law: field of an infinitely long, uniformly charged straight wire

Asked 2023 (2m)

NCERT §1.14.1, Eq. 1.32.



Gaussian surface: a cylinder of radius r and length l with the wire as its axis.

- By symmetry, $\mathbf{E}$ is radial (in the plane normal to the wire) and its magnitude depends only on r .
- Flux through the two flat ends is zero, because $\mathbf{E}$ is parallel to them. On the curved surface $\mathbf{E}$ is normal to the surface and constant:

$$\Phi = E \times 2\pi r l$$

- Charge enclosed = λl . Gauss's law:

$$E \times 2\pi r l = \frac{\lambda l}{\epsilon_0}$$

$$E = \frac{\lambda}{2\pi\epsilon_0 r}, \quad \mathbf{E} = \frac{\lambda}{2\pi\epsilon_0 r} \hat{\mathbf{n}}$$

Directed outward if $\lambda > 0$. Only the enclosed charge λl enters Gauss's law, but the field is due to the whole wire; the wire being infinite is what makes $\mathbf{E}$ normal to the curved surface.

Common mistake: writing $1/r^2$. A line charge gives $E \propto 1/r$; a point charge gives $1/r^2$; a plane sheet gives no r dependence.

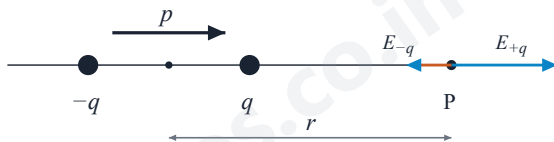


Also derived in NCERT, Chapter 1

1.5 Electric field of a dipole at a point on its axis

In NCERT

NCERT §1.10.1, Eqs. 1.13–1.15, 1.20.

P is on the axis at distance r from the centre, on the side of q .

$$1. \quad \mathbf{E}_{-q} = -\frac{q}{4\pi\epsilon_0(r+a)^2} \hat{\mathbf{p}}, \quad \mathbf{E}_{+q} = \frac{q}{4\pi\epsilon_0(r-a)^2} \hat{\mathbf{p}}$$

2. Adding:

$$\mathbf{E} = \frac{q}{4\pi\epsilon_0} \left[\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2} \right] \hat{\mathbf{p}} = \frac{q}{4\pi\epsilon_0} \frac{4ar}{(r^2-a^2)^2} \hat{\mathbf{p}}$$

3. For $r \gg a$, and with $p = 2qa$:

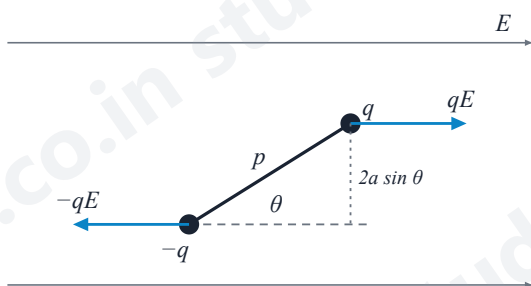
$$\mathbf{E} = \frac{4qa}{4\pi\epsilon_0 r^3} \hat{\mathbf{p}} = \frac{2\mathbf{p}}{4\pi\epsilon_0 r^3}$$

At the same large distance, the axial field is twice the equatorial field and points the other way.

1.6 Torque on a dipole in a uniform electric field: $\boldsymbol{\tau} = \mathbf{p} \times \mathbf{E}$

In NCERT

NCERT §1.11, Eq. 1.22.

Equal and opposite forces $q\mathbf{E}$ and $-q\mathbf{E}$ act at the two ends, forming a couple.1. Force $q\mathbf{E}$ on q and $-q\mathbf{E}$ on $-q$. Since $\mathbf{E}$ is uniform, the net force is zero.2. The forces act at different points, so they form a couple. The perpendicular distance between them (arm of the couple) is $2a \sin \theta$:

$$\tau = qE \times 2a \sin \theta = 2qaE \sin \theta = pE \sin \theta$$

3. The direction is normal to the plane of $\mathbf{p}$ and $\mathbf{E}$, the same as that of $\mathbf{p} \times \mathbf{E}$:

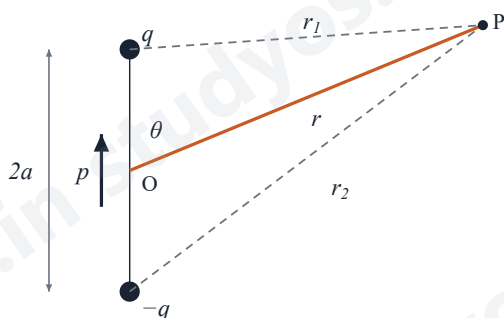
$$\boldsymbol{\tau} = \mathbf{p} \times \mathbf{E}$$

The torque tends to align $\mathbf{p}$ with $\mathbf{E}$; it is zero when they are parallel. In a non-uniform field there is also a net force.

2 Electrostatic Potential and Capacitance

2.1 Electric potential due to a dipole at a far point

Asked 2024 (5m) · 2025 (5m)

2025 asked for the axial and equatorial cases at distance $x \gg a$, which are the special cases at the end. NCERT §2.4, Eqs. 2.9–2.16.P is at distance r from the centre O, at angle θ to the dipole moment $\mathbf{p}$.1. Potential obeys superposition, so with r_1, r_2 the distances of P from q and $-q$:

$$V = \frac{1}{4\pi\epsilon_0} \left(\frac{q}{r_1} - \frac{q}{r_2} \right)$$

2. By geometry:

$$r_1^2 = r^2 + a^2 - 2ar \cos \theta, \quad r_2^2 = r^2 + a^2 + 2ar \cos \theta$$

3. For $r \gg a$, keep terms only to first order in a/r :

$$r_1^2 \cong r^2 \left(1 - \frac{2a \cos \theta}{r} \right), \quad r_2^2 \cong r^2 \left(1 + \frac{2a \cos \theta}{r} \right)$$



4. Binomial theorem, to first order:

$$\frac{1}{r_1} \cong \frac{1}{r} \left(1 + \frac{a}{r} \cos \theta \right), \quad \frac{1}{r_2} \cong \frac{1}{r} \left(1 - \frac{a}{r} \cos \theta \right)$$

5. Substituting, with $p = 2qa$:

$$V = \frac{q}{4\pi\epsilon_0} \frac{2a \cos \theta}{r^2} = \frac{p \cos \theta}{4\pi\epsilon_0 r^2}$$

$$V = \frac{1}{4\pi\epsilon_0} \frac{\mathbf{p} \cdot \hat{\mathbf{r}}}{r^2} \quad (r \gg a)$$

On the axis ($\theta = 0$ or π): $V = \pm \frac{p}{4\pi\epsilon_0 r^2}$. **On the equatorial line** ($\theta = \pi/2$): $V = 0$.

Common mistake: writing $1/r$. A dipole's potential falls off as $1/r^2$ (and its field as $1/r^3$); a single charge's potential falls as $1/r$.

2.2 Capacitance of a parallel plate capacitor (air between the plates)

Asked 2026 (5m)

NCERT §2.12, Eqs. 2.39–2.43. Uses the plane-sheet field from derivation 1.1.

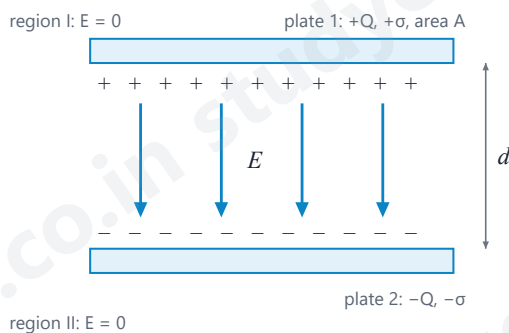


Plate separation d is small compared with the plate size ($d^2 \ll A$), so each plate acts like an infinite sheet.

1. Plate 1 has surface charge density $\sigma = Q/A$, plate 2 has $-\sigma$. Each produces a field $\sigma/2\epsilon_0$ (derivation 1.1).
2. Outside the plates (regions I and II) the two fields cancel:

$$E = \frac{\sigma}{2\epsilon_0} - \frac{\sigma}{2\epsilon_0} = 0$$

3. Between the plates they add, pointing from the positive to the negative plate:

$$E = \frac{\sigma}{2\epsilon_0} + \frac{\sigma}{2\epsilon_0} = \frac{\sigma}{\epsilon_0} = \frac{Q}{\epsilon_0 A}$$

4. The field is uniform, so the potential difference is:

$$V = Ed = \frac{1}{\epsilon_0} \frac{Qd}{A}$$

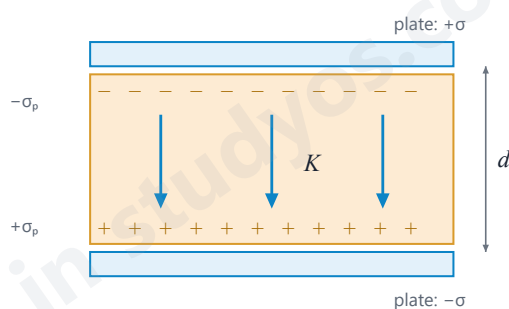
$$C = \frac{Q}{V} = \frac{\epsilon_0 A}{d}$$

Common mistake: using $\sigma/2\epsilon_0$ for the field between the plates. Inside, the fields of both plates add up to σ/ϵ_0 .

2.3 Parallel plate capacitor with a dielectric: $C = \frac{K\epsilon_0 A}{d}$

Asked 2024 (5m)

Dielectric fully fills the gap. NCERT §2.13, Eqs. 2.46–2.54.



The polarised dielectric acts like two sheets with induced charge densities $\mp\sigma_p$ on its faces, which weaken the field inside.

1. Without the dielectric: $E_0 = \sigma/\epsilon_0$, $V_0 = E_0 d$, so $C_0 = \epsilon_0 A/d$.

2. With the dielectric, the net surface charge density is $\pm(\sigma - \sigma_p)$:

$$E = \frac{\sigma - \sigma_p}{\epsilon_0}, \quad V = Ed = \frac{\sigma - \sigma_p}{\epsilon_0} d$$

3. For a linear dielectric, σ_p is proportional to σ , so we write $\sigma - \sigma_p = \sigma/K$ with $K > 1$:

$$V = \frac{\sigma d}{\epsilon_0 K} = \frac{Qd}{A\epsilon_0 K}$$

$$C = \frac{Q}{V} = \frac{\epsilon_0 K A}{d} = KC_0$$



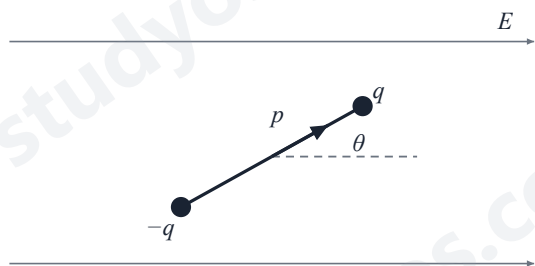
$K = C/C_0$ is the dielectric constant: the factor by which filling the gap with the dielectric increases the capacitance. $\epsilon = \epsilon_0 K$ is the permittivity of the medium.

Common mistake: using this for a slab that only partly fills the gap. Then the field is E_0 in the air part and E_0/K in the slab, and you add the two potential drops (NCERT Example 2.8).

2.4 Potential energy of a dipole in a uniform electric field: $U = -\mathbf{p} \cdot \mathbf{E}$

Asked 2024 (5m)

Asked with "when is it maximum and minimum?". NCERT §2.8.3, Eqs. 2.30–2.32.



The field exerts a torque $\tau = \mathbf{p} \times \mathbf{E}$ (derivation 1.6) that tries to align $\mathbf{p}$ with $\mathbf{E}$.

1. An external torque τ_{ext} just balances $\mathbf{p} \times \mathbf{E}$ and turns the dipole slowly (no angular acceleration) from θ_0 to θ_1 .

Work done:

$$W = \int_{\theta_0}^{\theta_1} \tau_{\text{ext}}(\theta) d\theta = \int_{\theta_0}^{\theta_1} pE \sin \theta d\theta$$

$$W = pE(\cos \theta_0 - \cos \theta_1)$$

2. This work is stored as potential energy. Choosing $U = 0$ at $\theta_0 = \pi/2$:

$$U(\theta) = pE \left(\cos \frac{\pi}{2} - \cos \theta \right)$$

$$U(\theta) = -pE \cos \theta = -\mathbf{p} \cdot \mathbf{E}$$

Minimum $U = -pE$ at $\theta = 0$ ($\mathbf{p}$ along $\mathbf{E}$, stable equilibrium). **Maximum** $U = +pE$ at $\theta = \pi$ ($\mathbf{p}$ opposite to $\mathbf{E}$, unstable equilibrium).

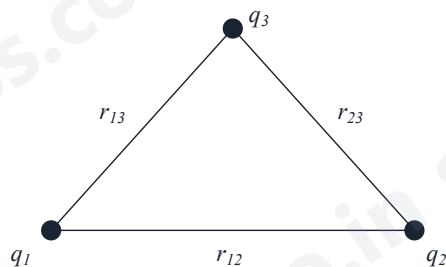
Common mistake: saying U is maximum at $\theta = 90^\circ$. That is where the torque is maximum; U is zero there.

2.5 Potential energy of a system of two and three point charges

Asked 2023 (2m)

Asked for q , $2q$ and $-3q$ at the corners of an equilateral triangle (worked below). NCERT §2.7, Eqs. 2.22–2.26.





The charges are brought in one at a time from infinity.

1. Bringing q_1 from infinity needs no work: there is no field yet.
2. Bringing q_2 to $\mathbf{r}_2$ costs q_2 times the potential of q_1 there. For two charges,

$$U = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{12}}$$

3. Bringing q_3 costs $q_3 V_{1,2}(\mathbf{r}_3)$:

$$q_3 V_{1,2}(\mathbf{r}_3) = \frac{1}{4\pi\epsilon_0} \left(\frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}} \right)$$

4. Adding the work in each step:

$$U = \frac{1}{4\pi\epsilon_0} \left(\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}} \right)$$

2023 question: $q, 2q, -3q$ on a triangle of side a : $U = \frac{1}{4\pi\epsilon_0 a} (2q^2 - 3q^2 - 6q^2) = -\frac{7q^2}{4\pi\epsilon_0 a}$.

Common mistake: counting each pair twice. There is exactly one term per pair of charges.

Also derived in NCERT, Chapter 2

2.6 Potential due to a point charge: $V = \frac{Q}{4\pi\epsilon_0 r}$

In NCERT

NCERT §2.3, Eqs. 2.5–2.8.

1. Bring a unit positive test charge from infinity to P along the radial line. At distance r' , the electrostatic force on it is $\frac{Q}{4\pi\epsilon_0 r'^2} \hat{\mathbf{r}}'$.
2. Work done against this force from r' to $r' + \Delta r'$: $\Delta W = -\frac{Q}{4\pi\epsilon_0 r'^2} \Delta r'$ (positive, since $\Delta r' < 0$).
3. Total work from $r' = \infty$ to $r' = r$:

$$W = -\int_{\infty}^r \frac{Q}{4\pi\epsilon_0 r'^2} dr' = \frac{Q}{4\pi\epsilon_0 r'} \Big|_{\infty}^r = \frac{Q}{4\pi\epsilon_0 r}$$

$$V(r) = \frac{Q}{4\pi\epsilon_0 r}$$

True for either sign of Q ; the potential at infinity is taken as zero.

2.7 Relation between field and potential: $|\mathbf{E}| = -\frac{\delta V}{\delta l}$

In NCERT

NCERT §2.6.1, Eqs. 2.20–2.21.

1. Take two close equipotential surfaces A (potential V) and B (potential $V + \delta V$), with δl the perpendicular distance between them.
2. Moving a unit positive charge from B to A against the field takes work $|\mathbf{E}| \delta l$, which equals $V_A - V_B$:

$$|\mathbf{E}| \delta l = V - (V + \delta V) = -\delta V$$

$$|\mathbf{E}| = -\frac{\delta V}{\delta l} = +\frac{|\delta V|}{\delta l}$$

So the field points in the direction in which the potential decreases most steeply, and its size is the potential change per unit distance normal to the equipotential surface.



2.8 Capacitors in series and in parallel

In NCERT

NCERT §2.14, Eqs. 2.55–2.67.

Series. Every capacitor carries the same charge Q (otherwise there would be a field in the connecting wire). The voltages add:

$$V = V_1 + V_2 = \frac{Q}{C_1} + \frac{Q}{C_2} \Rightarrow \frac{V}{Q} = \frac{1}{C_1} + \frac{1}{C_2}$$

The combination has charge Q and voltage V , so its capacitance is $C = Q/V$, giving $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$.

Parallel. Every capacitor has the same voltage V . The charges add:

$$Q = Q_1 + Q_2 = C_1V + C_2V \Rightarrow C = C_1 + C_2$$

$$\text{Series: } \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \dots \quad \text{Parallel: } C = C_1 + C_2 + \dots$$

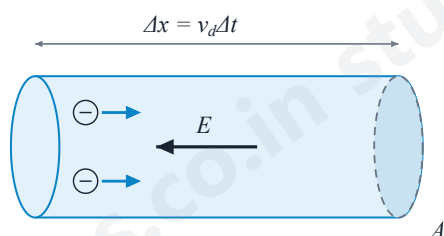
Common mistake: mixing these up with resistors. For capacitors, series uses reciprocals and parallel adds directly; for resistors it's the other way round.

Energy stored in a capacitor is "no derivation, formulae only" in the CBSE 2026-27 syllabus: $U = \frac{Q^2}{2C} = \frac{1}{2}CV^2 = \frac{1}{2}QV$, and energy density $u = \frac{1}{2}\epsilon_0 E^2$.

3 Current Electricity**3.1 Drift velocity $\mathbf{v}_d = -\frac{e\mathbf{E}}{m}\tau$ and current $I = neAv_d$**

Asked 2025 (3m) · 2026 (2m, 3m, 5m)

The most-asked Current Electricity derivation: 2026 asked it in four different papers. NCERT §3.5, Eqs. 3.14–3.18.



All free electrons within $|v_d|\Delta t$ of the area A cross it in time Δt . Electrons drift opposite to $\mathbf{E}$.

- Without a field, electrons move randomly; their average velocity is zero: $\frac{1}{N} \sum \mathbf{v}_i = 0$.
- With a field $\mathbf{E}$, each electron (charge $-e$) accelerates at $\mathbf{a} = -e\mathbf{E}/m$. If t_i is the time since its last collision and $\mathbf{v}_i$ its velocity just after it:

$$\mathbf{V}_i = \mathbf{v}_i - \frac{e\mathbf{E}}{m} t_i$$

- Average over all electrons. $(\mathbf{v}_i)_{\text{avg}} = 0$ and the average of t_i is the relaxation time τ :

$$\mathbf{v}_d = (\mathbf{v}_i)_{\text{avg}} - \frac{e\mathbf{E}}{m} (t_i)_{\text{avg}} = -\frac{e\mathbf{E}}{m} \tau$$

- With n free electrons per unit volume, the number crossing area A in time Δt is $nA|v_d|\Delta t$. The charge they carry is $I \Delta t$:

$$I \Delta t = neA|v_d| \Delta t$$

$$\mathbf{v}_d = -\frac{e\mathbf{E}}{m} \tau, \quad I = neAv_d, \quad j = \frac{I}{A} = nev_d$$

The drift velocity is constant in time even though each electron is accelerated, because collisions keep resetting it. Typical v_d is about 1 mm/s.

Common mistake: losing the minus sign. Electrons drift opposite to $\mathbf{E}$, but the current is along $\mathbf{E}$.



3.2 Ohm's law from drift: $\mathbf{j} = \frac{ne^2\tau}{m}\mathbf{E}$, resistivity $\rho = \frac{m}{ne^2\tau}$

Asked 2024 (3m, 2m) · 2025 (3m)

Asked as "show that $\mathbf{j} = \alpha\mathbf{E}$ ", "show that $R = \frac{ml}{ne^2\tau A}$ " and "derive the resistivity in terms of n and τ ". NCERT §3.4–3.5, Eqs. 3.11–3.23.

1. Ohm's law in terms of $\mathbf{E}$ and $\mathbf{j}$: for a conductor of length l and area A , $V = El$, $I = jA$ and $R = \rho l/A$. So $El = jA \cdot \frac{\rho l}{A}$, i.e. $E = j\rho$, or

$$\mathbf{j} = \sigma\mathbf{E}, \quad \sigma = 1/\rho$$

2. From derivation 3.1, $I = neA|v_d|$ and $|v_d| = \frac{eE\tau}{m}$. So

$$I \Delta t = \frac{e^2 A}{m} \tau n \Delta t |\mathbf{E}| \Rightarrow |\mathbf{j}| = \frac{I}{A} = \frac{ne^2}{m} \tau |\mathbf{E}|$$

3. $\mathbf{j}$ is parallel to $\mathbf{E}$, so in vector form $\mathbf{j} = \frac{ne^2\tau}{m}\mathbf{E}$. Comparing with $\mathbf{j} = \sigma\mathbf{E}$:

$$\sigma = \frac{ne^2\tau}{m}, \quad \rho = \frac{m}{ne^2\tau}, \quad R = \frac{\rho l}{A} = \frac{ml}{ne^2\tau A}$$

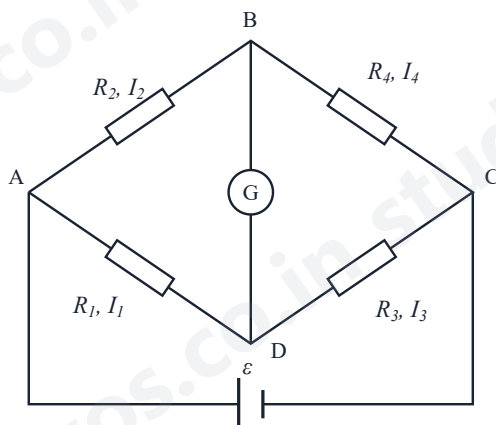
This is Ohm's law ($j \propto E$) coming out of a simple picture, assuming n and τ don't depend on E . Resistivity rises with temperature because τ falls (more frequent collisions).

Common mistake: writing ρ with e instead of e^2 . One e comes from the charge each electron carries, the other from the force eE that makes it drift.

3.3 Balance condition of a Wheatstone bridge: $\frac{R_2}{R_1} = \frac{R_4}{R_3}$

Asked 2026 (3m, 5m)

NCERT §3.13, Eqs. 3.62–3.64. Labels follow NCERT Fig. 3.18.



Battery across A and C; galvanometer G across B and D. Balanced means $I_g = 0$.

1. At balance no current flows through G ($I_g = 0$).

Kirchhoff's junction rule at D and B then gives

$$I_1 = I_3, \quad I_2 = I_4$$

2. Loop rule for loop ADDB (the G arm has no current, so no drop across it):

$$-I_1 R_1 + 0 + I_2 R_2 = 0 \Rightarrow \frac{I_1}{I_2} = \frac{R_2}{R_1}$$

3. Loop rule for loop CBDC, using $I_3 = I_1$, $I_4 = I_2$:

$$I_2 R_4 + 0 - I_1 R_3 = 0 \Rightarrow \frac{I_1}{I_2} = \frac{R_4}{R_3}$$

$$\frac{R_2}{R_1} = \frac{R_4}{R_3}$$

So an unknown R_4 can be found as $R_4 = R_3 R_2 / R_1$ by adjusting R_3 until G shows no deflection. The meter bridge uses this principle.

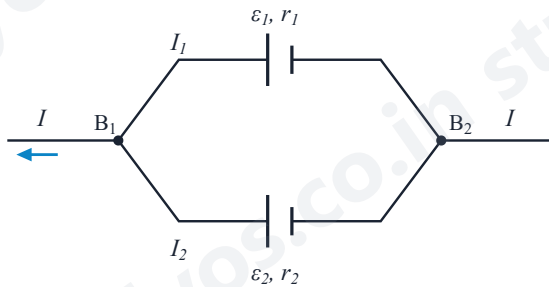
Common mistake: pairing the wrong arms. The condition is "ratio of the two arms on one side of G = ratio of the two arms on the other side"; check it against your own labels.



3.4 Two cells in parallel: equivalent emf and internal resistance

Asked 2025 (3m)

NCERT §3.11, Eqs. 3.48–3.57.



The cells' currents I_1 and I_2 leave their positive terminals and join at B_1 .

1. Charge conservation at B_1 : $I = I_1 + I_2$.2. Both cells have the same terminal voltage $V = V(B_1) - V(B_2)$:

$$V = \varepsilon_1 - I_1 r_1, \quad V = \varepsilon_2 - I_2 r_2$$

3. Combining:

$$I = \frac{\varepsilon_1 - V}{r_1} + \frac{\varepsilon_2 - V}{r_2} = \left(\frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2} \right) - V \left(\frac{1}{r_1} + \frac{1}{r_2} \right)$$

4. Solving for V :

$$V = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2} - I \frac{r_1 r_2}{r_1 + r_2}$$

5. For one equivalent cell, $V = \varepsilon_{eq} - I r_{eq}$. Comparing:

$$\varepsilon_{eq} = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2}, \quad r_{eq} = \frac{r_1 r_2}{r_1 + r_2}$$

Simpler form: $\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2}$ and $\frac{\varepsilon_{eq}}{r_{eq}} = \frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2}$.

Common mistake: adding the emfs. In parallel the emfs don't add; the equivalent emf is a weighted average of the two.

Also derived in NCERT, Chapter 3**3.5 Two cells in series:** $\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2$, $r_{eq} = r_1 + r_2$

In NCERT

NCERT §3.11, Eqs. 3.41–3.47.

1. With current I through both cells (negative terminal of the first joined to the positive of the second, at B):

$$V_{AB} = \varepsilon_1 - I r_1, \quad V_{BC} = \varepsilon_2 - I r_2$$

2. Adding: $V_{AC} = (\varepsilon_1 + \varepsilon_2) - I(r_1 + r_2)$. Comparing with $V_{AC} = \varepsilon_{eq} - I r_{eq}$:

$$\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2, \quad r_{eq} = r_1 + r_2$$

If the second cell is connected the other way round (negatives joined), $\varepsilon_{eq} = \varepsilon_1 - \varepsilon_2$; the internal resistances still add.

3.6 Mobility: $\mu = \frac{e\tau}{m}$

In NCERT

NCERT §3.5.1, Eqs. 3.24–3.25.

Mobility is the magnitude of the drift velocity per unit field, $\mu = |v_d|/E$ (unit m^2/Vs). From derivation 3.1, $v_d = \frac{e\tau E}{m}$, so

$$\mu = \frac{v_d}{E} = \frac{e\tau}{m}$$

3.7 Terminal voltage and current with internal resistance: $I = \frac{\varepsilon}{R+r}$

In NCERT

NCERT §3.10, Eqs. 3.38–3.40.

A cell of emf ε and internal resistance r drives current I through an external resistor R . The drop inside the cell is Ir , so the terminal voltage is $V = \varepsilon - Ir$. Since $V = IR$: $IR = \varepsilon - Ir$.



$$V = \varepsilon - Ir, \quad I = \frac{\varepsilon}{R + r}$$

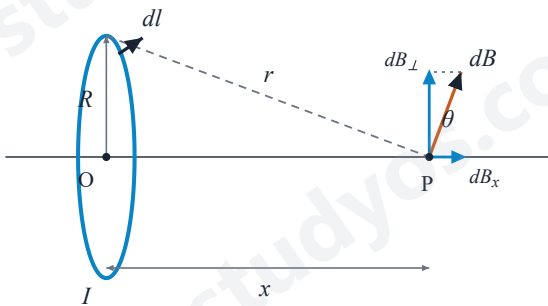
The largest current is $I_{\max} = \varepsilon/r$ (at $R = 0$). That is why a low-voltage supply meant to give large currents must have a very small internal resistance.

4 Moving Charges and Magnetism

4.1 Biot-Savart law: field on the axis of a circular current loop, and at its centre

Asked 2023 (5m) · 2025 (3m) · 2026 (3m)

2023 asked for the centre, 2025 for the axis and centre, 2026 for a coil of N turns. NCERT §4.5, Eqs. 4.8–4.12.



Loop of radius R in the y - z plane; P is on its axis at distance x from the centre O.

1. Biot-Savart law for an element $d\mathbf{l}$:

$$d\mathbf{B} = \frac{\mu_0}{4\pi} \frac{I |d\mathbf{l} \times \mathbf{r}|}{r^3}$$

2. Here $r^2 = x^2 + R^2$, and every element $d\mathbf{l}$ is perpendicular to $\mathbf{r}$, so $|d\mathbf{l} \times \mathbf{r}| = r dl$:

$$dB = \frac{\mu_0}{4\pi} \frac{I dl}{x^2 + R^2}$$

3. The components $dB_{\perp}$ from diametrically opposite elements cancel. Only $dB_x = dB \cos \theta$ survives, with

$$\cos \theta = \frac{R}{(x^2 + R^2)^{1/2}} \Rightarrow dB_x = \frac{\mu_0 I dl}{4\pi} \frac{R}{(x^2 + R^2)^{3/2}}$$

4. Summing dl over the loop gives $2\pi R$:

$$\mathbf{B} = \frac{\mu_0 I R^2}{2(x^2 + R^2)^{3/2}} \hat{\mathbf{i}}, \quad \text{centre } (x = 0) : \mathbf{B}_0 = \frac{\mu_0 I}{2R} \hat{\mathbf{i}}$$

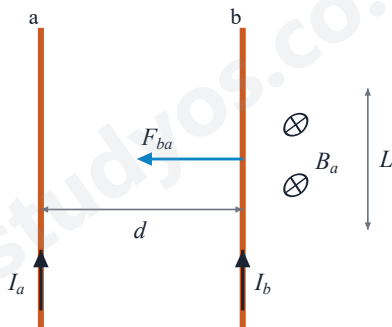
For a coil of N closely wound turns, multiply by N : $B = \frac{\mu_0 N I R^2}{2(x^2 + R^2)^{3/2}}$. Direction by the right-hand thumb rule: curl the fingers along the current; the thumb gives $\mathbf{B}$.

Common mistake: adding the full $d\mathbf{B}$ of every element. The perpendicular parts cancel in pairs; only $d\mathbf{B} \cos \theta$ adds up.

4.2 Force between two long parallel current-carrying conductors; definition of the ampere

Asked 2024 (3m) · 2026 (3m)

2024 asked for currents in opposite directions, 2026 for the same direction. NCERT §4.8, Eqs. 4.17–4.19.



Wire a sets up $\mathbf{B}_a$ (into the page at b). The force on b points towards a: parallel currents attract.

1. Conductor a produces the same field at every point of b. From Ampere's law (derivation 4.5):

$$B_a = \frac{\mu_0 I_a}{2\pi d}$$

2. A length L of b carrying I_b feels a force $F = I_b L B_a$ (since $\mathbf{B}_a \perp \mathbf{b}$), directed towards a:

$$F_{ba} = I_b L B_a = \frac{\mu_0 I_a I_b}{2\pi d} L$$

3. Similarly, a feels an equal and opposite force: $\mathbf{F}_{ba} = -\mathbf{F}_{ab}$. Force per unit length:

$$f_{ba} = \frac{F_{ba}}{L} = \frac{\mu_0 I_a I_b}{2\pi d}$$



Nature: parallel currents attract; antiparallel currents repel.

Ampere: the current which, in each of two very long parallel wires 1 m apart in vacuum, produces a force of 2×10^{-7} N per metre of length.

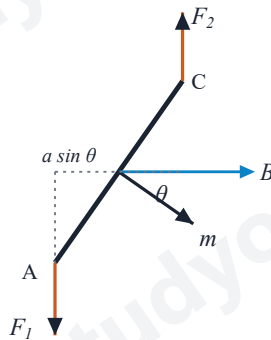
Common mistake: "like currents repel, like charges repel". It's the opposite for currents: same-direction currents attract.

4.3 Torque on a rectangular current loop in a uniform magnetic field:

Asked 2024 (3m) · 2026 (5m)

$$\tau = \mathbf{m} \times \mathbf{B}$$

Both years asked for the vector form with a diagram. NCERT §4.9.1, Eqs. 4.20–4.24.



View along the loop's length. Arms AB and CD (length b) carry forces F_1 and F_2 , each $\perp$ to $\mathbf{B}$. θ is the angle between the normal $\mathbf{m}$ and $\mathbf{B}$.

- Forces on arms BC and DA are equal, opposite and collinear (along the loop's axis), so they cancel: no force, no torque.
- Forces on arms AB and CD (length b) are equal and opposite: $F_1 = F_2 = IbB$. The net force is zero, but they are not collinear, so they form a couple.
- The arm of the couple is $a \sin \theta$ (each force acts at $\frac{a}{2} \sin \theta$ from the axis):

$$\tau = F_1 \frac{a}{2} \sin \theta + F_2 \frac{a}{2} \sin \theta = IabB \sin \theta = IAB \sin \theta$$

- Define the magnetic moment $\mathbf{m} = I\mathbf{A}$, with $\mathbf{A}$ along the normal by the right-hand thumb rule. Then:

$$\tau = \mathbf{m} \times \mathbf{B}, \quad \mathbf{m} = NIA \text{ for } N \text{ turns}$$

When the plane of the loop is along $\mathbf{B}$ ($\theta = 90^\circ$), $\tau = IAB$ is maximum. It is zero when $\mathbf{m}$ is parallel (stable) or antiparallel (unstable) to $\mathbf{B}$. Compare $\tau = \mathbf{p} \times \mathbf{E}$ (derivation 1.6).

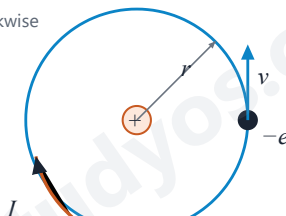
Common mistake: taking θ as the angle between the plane of the loop and $\mathbf{B}$. In $\tau = mB \sin \theta$, θ is measured from the normal ($\mathbf{m}$).

4.4 Magnetic moment of an orbiting electron: $\mu_e = -\frac{e}{2m_e} \mathbf{L}$

Asked 2024 (3m) · 2025 (3m) · Not in NCERT

This section was dropped from the rationalised NCERT book, but CBSE asked it in both years, including the gyromagnetic ratio. Learn it from here.

electron moves anticlockwise
current I is clockwise



$\mathbf{L}$ out of page ($\odot$), μ into page ($\otimes$)

The electron's orbit is a tiny current loop. Because its charge is negative, the current flows opposite to its motion.

- An electron (charge $-e$, mass m_e) moves with speed v in a circle of radius r . Its period is $T = 2\pi r/v$, so the equivalent current is

$$I = \frac{e}{T} = \frac{ev}{2\pi r}$$

- Magnetic moment of this current loop (area πr^2):

$$\mu_e = I \pi r^2 = \frac{ev}{2\pi r} \pi r^2 = \frac{evr}{2}$$

- The orbital angular momentum is $L = m_e vr$, so $vr = L/m_e$:

$$\mu_e = \frac{e}{2m_e} L$$

- For the negative electron, the current is opposite to its motion, so μ_e points opposite to $\mathbf{L}$:



$$\mu_e = -\frac{e}{2m_e} \mathbf{L}$$

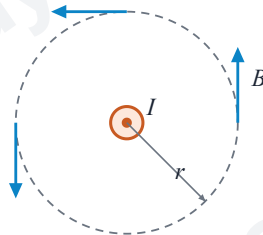
$$\text{gyromagnetic ratio: } \frac{\mu_e}{L} = \frac{e}{2m_e} = 8.8 \times 10^{10} \text{ C kg}^{-1}$$

Common mistake: dropping the minus sign in the vector form. It is there because the electron's charge is negative.

4.5 Ampere's circuital law: field of an infinitely long straight wire

Asked 2025 (3m)

Asked with "why Ampere's law and not Biot-Savart?" (answered below). NCERT §4.6, Eqs. 4.13–4.14.



wire perpendicular to page, current out of page ($\odot$)

Amperian loop: a circle of radius r centred on the wire. $\mathbf{B}$ is tangential and has the same magnitude all round it.

1. Ampere's circuital law: $\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I$, where I is the current enclosed by the loop.
2. By symmetry, on a circle of radius r around the wire, $\mathbf{B}$ is tangential and constant in magnitude, so $\oint \mathbf{B} \cdot d\mathbf{l} = B \times 2\pi r$.
3. The loop encloses the whole current I :

$$B \times 2\pi r = \mu_0 I$$

$$B = \frac{\mu_0 I}{2\pi r}$$

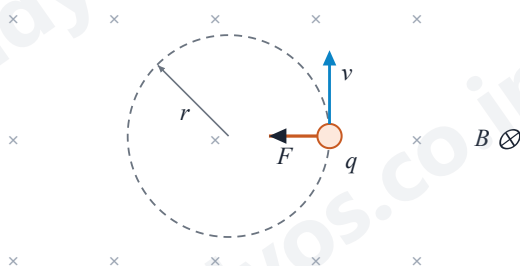
Why Ampere's law here? The wire has cylindrical symmetry, so we can pick a loop on which $\mathbf{B}$ is tangential and constant. The integral then reduces to $B \times 2\pi r$, with no integration over current elements as Biot-Savart would need.

Common mistake: drawing $\mathbf{B}$ pointing away from the wire. The field lines are circles around the wire (right-hand rule: thumb along the current, fingers curl along $\mathbf{B}$).

4.6 Charged particle in a uniform magnetic field: radius, frequency and helical path

Asked 2024 (5m)

Asked as "show that it follows a helical path; hence obtain its frequency of revolution". NCERT §4.3, Eqs. 4.5–4.6.



With $\mathbf{v} \perp \mathbf{B}$, the force $q\mathbf{v} \times \mathbf{B}$ is always perpendicular to $\mathbf{v}$ and points to the centre.

1. The magnetic force $q\mathbf{v} \times \mathbf{B}$ is perpendicular to $\mathbf{v}$: it does no work and changes only the direction of motion. With $\mathbf{v} \perp \mathbf{B}$ it acts as the centripetal force:

$$\frac{mv^2}{r} = qvB \Rightarrow r = \frac{mv}{qB}$$

2. Angular frequency $\omega = v/r$:

$$\omega = 2\pi\nu = \frac{qB}{m}, \quad T = \frac{2\pi m}{qB}$$

independent of the speed.

3. **Helix.** If $\mathbf{v}$ has a component $v_{\parallel}$ along $\mathbf{B}$, that component is unaffected, while the perpendicular component $v_{\perp}$ gives circular motion (radius $mv_{\perp}/qB$). The combination is a helix. Distance moved along $\mathbf{B}$ in one revolution (pitch):

$$r = \frac{mv_{\perp}}{qB}, \quad \nu = \frac{qB}{2\pi m}, \quad p = v_{\parallel} T = \frac{2\pi m v_{\parallel}}{qB}$$



Common mistake: using the full speed v for the helix radius. Only $v_{\perp}$ goes into the radius; only $v_{\parallel}$ goes into the pitch.

Also derived in NCERT, Chapter 4

4.7 Moving coil galvanometer: current sensitivity, and conversion to ammeter and voltmeter

In NCERT

NCERT §4.10, Eqs. 4.25–4.28.

1. The coil (N turns, area A) sits in a radial field, so $\sin \theta = 1$ and the magnetic torque is $NIAB$. A spring gives a restoring torque $k\phi$. At equilibrium:

$$k\phi = NIAB \Rightarrow \phi = \left(\frac{NAB}{k} \right) I$$

2. **Current sensitivity** (deflection per unit current) and **voltage sensitivity** (deflection per unit voltage, with coil resistance R):

$$\frac{\phi}{I} = \frac{NAB}{k}, \quad \frac{\phi}{V} = \frac{NAB}{k} \cdot \frac{1}{R}$$

3. **Ammeter:** a small shunt resistance r_s is connected in parallel with the galvanometer (resistance R_G). The combination's resistance is $\frac{R_G r_s}{R_G + r_s} \simeq r_s$ when $R_G \gg r_s$, so most of the current bypasses the coil.

4. **Voltmeter:** a large resistance R is connected in series: total $R_G + R \simeq R$, so it draws very little current.

$$\phi = \frac{NAB}{k} I, \quad \text{ammeter: small } r_s \text{ in parallel,} \quad \text{voltmeter: large } R \text{ in series}$$

Doubling N doubles the current sensitivity, but usually doubles R too, so the voltage sensitivity stays the same.

Solenoid: the CBSE 2026-27 syllabus lists the straight solenoid as "only qualitative treatment", so its field ($B = \mu_0 n I$ inside) is a result to know, not a derivation to write.

5 Magnetism and Matter

The CBSE 2026-27 syllabus treats the bar magnet as an equivalent solenoid, the field of a bar magnet on its axis and equator, and the torque on a bar magnet all as "**qualitative treatment only**", so this chapter has no derivations to learn. The one derivation-style question in 2022–2026 (2025, 3 marks: magnetic moment of an orbiting electron, $\mu = -\frac{e}{2m}\mathbf{L}$) is covered in **derivation 4.4**. Know the results: field on the axis $B = \frac{\mu_0}{4\pi} \frac{2m}{r^3}$, on the equator $B = \frac{\mu_0}{4\pi} \frac{m}{r^3}$, torque $\tau = \mathbf{m} \times \mathbf{B}$.

6 Electromagnetic Induction

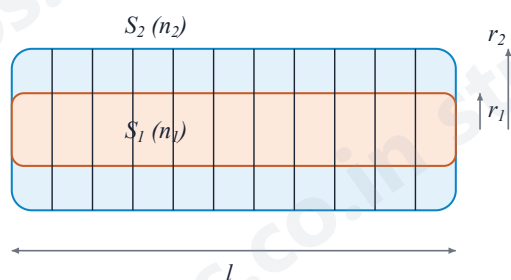
6.1 Mutual inductance: two co-axial solenoids, and two concentric coplanar loops

Asked 2023 (3m) · 2024 (5m) · 2025 (3m) · 2026 (3m)

2023, 2024 and 2025 asked the concentric loops (NCERT Example 6.8); 2026 asked a solenoid with a coil around it. NCERT §6.7.1,



Eqs. 6.7–6.12.



Inner solenoid S_1 (radius r_1 , n_1 turns/m) inside outer solenoid S_2 (radius r_2 , n_2 turns/m), both of length l .

(a) Co-axial solenoids.

1. Current I_2 in S_2 gives a uniform field $B = \mu_0 n_2 I_2$ inside it. The flux linkage with S_1 ($n_1 l$ turns, area πr_1^2) is

$$N_1 \Phi_1 = (n_1 l)(\pi r_1^2)(\mu_0 n_2 I_2)$$

2. By definition, $N_1 \Phi_1 = M_{12} I_2$, so $M_{12} = \mu_0 n_1 n_2 \pi r_1^2 l$.

3. Reverse case: current I_1 in S_1 sets up a field $\mu_0 n_1 I_1$ only inside S_1 , so the flux through S_2 also uses area πr_1^2 :

$$N_2 \Phi_2 = (n_2 l)(\pi r_1^2)(\mu_0 n_1 I_1), \text{ giving the same value.}$$

$$M_{12} = M_{21} = M = \mu_0 n_1 n_2 \pi r_1^2 l$$

- (b) Concentric coplanar loops**, radii $r_1 \ll r_2$. Current I_2 in the outer loop gives $B_2 = \frac{\mu_0 I_2}{2r_2}$ at its centre (derivation 4.1). The small loop sits in this nearly uniform field:

$$\Phi_1 = \pi r_1^2 B_2 = \frac{\mu_0 \pi r_1^2}{2r_2} I_2 \Rightarrow M = \frac{\mu_0 \pi r_1^2}{2r_2}$$

With a core of relative permeability μ_r , $M = \mu_r \mu_0 n_1 n_2 \pi r_1^2 l$. $M_{12} = M_{21}$ holds in general, which is useful when one of the two fluxes is hard to calculate.

Common mistake: using the outer radius r_2 in (a). The flux that links both coils passes through the inner solenoid's area, πr_1^2 .

6.2 Self-inductance of a long solenoid: $L = \mu_0 n^2 A l$

Asked 2023 (3m) · 2025 (3m) · 2026 (5m)

2026 asked it in terms of N total turns: $L = \mu_0 N^2 A / l$. NCERT §6.7.2, Eqs. 6.13–6.16.

1. Self-inductance is defined by $N \Phi_B = LI$, so the self-induced emf is $\varepsilon = -L \frac{dI}{dt}$.
2. A long solenoid (area A , length l , n turns per unit length) carrying current I has field $B = \mu_0 n I$ inside (edge effects neglected).
3. Total flux linkage, with nl turns:

$$N \Phi_B = (nl)(\mu_0 n I)(A) = \mu_0 n^2 A l I$$

$$L = \frac{N \Phi_B}{I} = \mu_0 n^2 A l = \frac{\mu_0 N^2 A}{l}$$

With a core of relative permeability μ_r (e.g. soft iron), $L = \mu_r \mu_0 n^2 A l$. L depends only on the geometry and the core material.

Common mistake: writing n instead of n^2 . One n comes from the field, the other from the number of turns the flux links.

6.3 Energy stored in an inductor $\frac{1}{2} L I^2$, and magnetic energy density $\frac{B^2}{2\mu_0}$

Asked 2025 (5m, 3m) · 2026 (3m)

Energy density is NCERT Example 6.9; 2025 and 2026 both asked it. NCERT §6.7.2, Eqs. 6.17–6.18.

1. Work must be done against the back emf ε to build up the current. Rate of doing work:

$$\frac{dW}{dt} = |\varepsilon| I = L I \frac{dI}{dt}$$

2. Total work to raise the current from 0 to I (resistive losses ignored):

$$W = \int dW = \int_0^I L I dI = \frac{1}{2} L I^2$$



3. **Energy density.** For a solenoid, $B = \mu_0 n I$ and $L = \mu_0 n^2 A l$:

$$U_B = \frac{1}{2} L I^2 = \frac{1}{2} (\mu_0 n^2 A l) \left(\frac{B}{\mu_0 n} \right)^2 = \frac{B^2}{2\mu_0} A l$$

4. The field fills volume $A l$, so the energy per unit volume is:

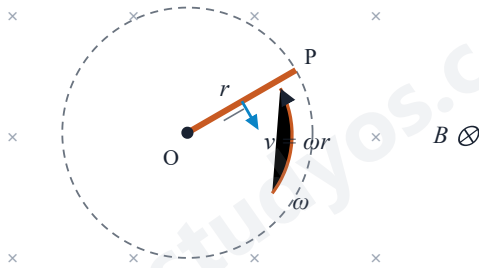
$$U = \frac{1}{2} L I^2, \quad u_B = \frac{U_B}{A l} = \frac{B^2}{2\mu_0}$$

$\frac{1}{2} L I^2$ mirrors $\frac{1}{2} m v^2$: L is electrical inertia. $u_B = B^2/2\mu_0$ matches $u_E = \frac{1}{2} \epsilon_0 E^2$ for the electric field, and both hold anywhere a field exists.

6.4 EMF induced in a rod rotating about one end: $\epsilon = \frac{1}{2} B \omega L^2$

Asked 2025 (3m)

Asked in three 2025 papers; the 2026 numerical (rod pivoted at one end) uses the same result. NCERT Example 6.6.



The rod OP (length L) turns about O with angular velocity ω in a plane perpendicular to $\mathbf{B}$.

1. Each element dr of the rod at distance r from O moves with speed $v = \omega r$, perpendicular to both $\mathbf{B}$ and the rod.
2. Motional emf across that element (derivation 6.5):

$$d\epsilon = B v dr = B \omega r dr$$

3. The elements are in series, so their emfs add along the rod:

$$\epsilon = \int_0^L B \omega r dr = B \omega \frac{L^2}{2}$$

$$\epsilon = \frac{1}{2} B \omega L^2 = \pi \nu B L^2$$

Alternative: the rod sweeps area $\frac{1}{2} L^2 \theta$, so $\epsilon = B \frac{d}{dt} \left(\frac{1}{2} L^2 \theta \right) = \frac{1}{2} B L^2 \omega$. For a wheel with many spokes, the emf is the same as for one spoke, because the spokes are in parallel.

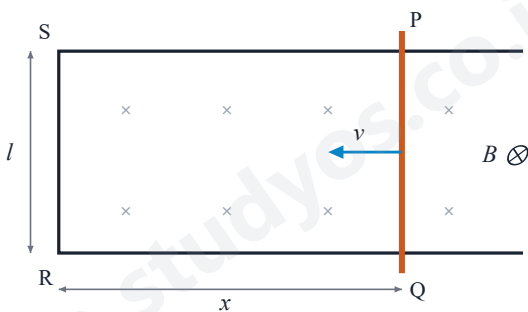
Common mistake: using $\epsilon = B L v$ with the tip speed ωL .

Different parts move at different speeds; the average speed $\omega L/2$ is what gives the factor $\frac{1}{2}$.

6.5 Motional emf $\epsilon = B l v$, and the energy argument (current, force, power)

Asked 2023 (3m) · 2025 (5m) · Energy part not in NCERT

$\epsilon = B l v$ is NCERT §6.6, Eq. 6.5. The energy part (current, force and power needed) was dropped from the rationalised book, but 2023 and 2025 asked it.



Rod PQ (length l , resistance r) slides with speed v on rails; the loop's area $l x$ changes.

1. Flux through PQRS: $\Phi_B = B l x$. With $dx/dt = -v$:

$$\epsilon = - \frac{d\Phi_B}{dt} = - B l \frac{dx}{dt} = B l v$$

2. **Lorentz-force view:** each charge q in the rod feels force $q v B$ along it. Work from P to Q is $W = q v B l$, so $\epsilon = W/q = B l v$.

3. **Energy:** with total resistance r , the current is $I = \frac{B l v}{r}$.

The field pushes back on the current-carrying rod with force $F = I l B = \frac{B^2 l^2 v}{r}$, opposing the motion (Lenz's law).



4. To keep v constant, an external agent must supply power:

$$P = Fv = \frac{B^2 l^2 v^2}{r}$$

5. Joule heating in the circuit: $P_J = I^2 r = \frac{B^2 l^2 v^2}{r}$, the same. The mechanical work becomes electrical energy and then heat.

$$\varepsilon = Blv, \quad I = \frac{Blv}{r}, \quad P = \frac{B^2 l^2 v^2}{r}$$

Common mistake: treating the emf as "free energy". The retarding force means work must be done on the rod; that work is exactly the electrical energy produced, which is why Lenz's law follows from energy conservation.

6.6 EMF of a coil rotating in a uniform field (AC generator): $\varepsilon = NBA\omega \sin \omega t$

Asked 2024 (5m)

NCERT §6.8, Eqs. 6.19–6.21.

1. A coil of N turns and area A rotates with angular speed ω in a uniform field $\mathbf{B}$. The angle between $\mathbf{B}$ and the area vector is $\theta = \omega t$ (taking $\theta = 0$ at $t = 0$).
2. Flux through one turn: $\Phi_B = BA \cos \theta = BA \cos \omega t$.
3. Faraday's law:

$$\varepsilon = -N \frac{d\Phi_B}{dt} = -NBA \frac{d}{dt}(\cos \omega t) = NBA\omega \sin \omega t$$

$$\varepsilon = \varepsilon_0 \sin \omega t = \varepsilon_0 \sin 2\pi \nu t, \quad \varepsilon_0 = NBA\omega$$

The emf is largest when the plane of the coil is parallel to $\mathbf{B}$ ($\theta = 90^\circ$ or 270°), because the flux is changing fastest there, even though the flux itself is zero.

6.7 Induced charge depends only on the change in flux: $Q = \frac{\Delta\Phi}{R}$

Asked 2024 (3m) · Not in NCERT

Follows directly from Faraday's law; not worked out in the book.

1. Induced emf in a coil of N turns: $\varepsilon = -N \frac{d\Phi}{dt}$. With circuit resistance R , the current is $I = \frac{\varepsilon}{R} = -\frac{N}{R} \frac{d\Phi}{dt}$.
2. Charge flowing in time dt : $dq = I dt = -\frac{N}{R} d\Phi$.
3. Integrating while the flux changes from Φ_1 to Φ_2 :

$$Q = \frac{N(\Phi_1 - \Phi_2)}{R} = \frac{N|\Delta\Phi|}{R}$$

dt has cancelled out: changing the flux quickly gives a bigger current for a shorter time, but the same total charge.

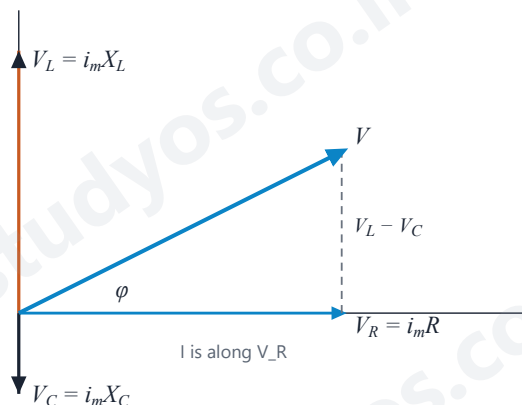


7 Alternating Current

7.1 Series LCR circuit: impedance and phase angle from the phasor diagram

Asked 2023 (3m) · 2024 (5m) · 2026 (5m)

2024 asked the RC case, which is this with $X_L = 0$. NCERT §7.6.1, Eqs. 7.21–7.27.



Drawn for $X_L > X_C$. V_R is in phase with I , V_L leads I by $\pi/2$, V_C lags by $\pi/2$.

1. In series, the same current $i = i_m \sin(\omega t + \phi)$ flows through R, L and C. Voltage amplitudes:

$$v_{Rm} = i_m R, \quad v_{Lm} = i_m X_L, \quad v_{Cm} = i_m X_C$$

2. V_R is along I ; V_L and V_C are perpendicular to it and opposite to each other, so they combine to a single phasor of length $|v_{Cm} - v_{Lm}|$.

3. Kirchhoff's loop rule in phasor form, $V_L + V_R + V_C = V$. V is the hypotenuse of a right triangle:

$$v_m^2 = v_{Rm}^2 + (v_{Cm} - v_{Lm})^2$$

$$v_m^2 = i_m^2 [R^2 + (X_C - X_L)^2]$$

4. Writing $i_m = v_m/Z$:

$$Z = \sqrt{R^2 + (X_C - X_L)^2}, \quad \tan \phi = \frac{X_C - X_L}{R}$$

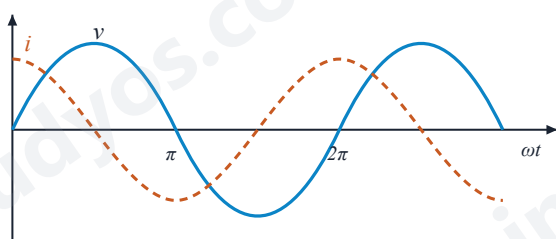
$X_C > X_L$: current leads (capacitive). $X_L > X_C$: current lags (inductive). RC circuit: $Z = \sqrt{R^2 + X_C^2}$. Minimum impedance $Z = R$ at resonance (derivation 7.3).

Common mistake: adding the voltage amplitudes directly, $v_R + v_L + v_C$. They are out of phase, so they add as vectors (NCERT Example 7.6).

7.2 AC voltage across a capacitor: current leads by $\pi/2$, $X_C = \frac{1}{\omega C}$

Asked 2023 (3m)

Asked with "plot i against ωt ". NCERT §7.5, Eqs. 7.15–7.19.



$v = v_m \sin \omega t$ (solid) and i (dashed). The current peaks a quarter-cycle before the voltage.

1. With charge q on the capacitor, $v = q/C$. Kirchhoff's loop rule:

$$v_m \sin \omega t = \frac{q}{C} \Rightarrow q = C v_m \sin \omega t$$

2. Current:

$$i = \frac{dq}{dt} = \omega C v_m \cos \omega t$$

$$i = i_m \sin \left(\omega t + \frac{\pi}{2} \right), \quad i_m = \omega C v_m$$

3. Writing $i_m = \frac{v_m}{1/\omega C}$, the term $1/\omega C$ plays the role of resistance:

$$X_C = \frac{1}{\omega C}, \quad i_m = \frac{v_m}{X_C}, \quad i = i_m \sin \left(\omega t + \frac{\pi}{2} \right)$$

Power: $p = iv = \frac{i_m v_m}{2} \sin 2\omega t$, whose average over a cycle is zero. A pure capacitor draws no average power.

Common mistake: mixing up lead and lag. Capacitor: current leads. Inductor: current lags (derivation 7.4).



7.3 Average power in a series LCR circuit $P = VI \cos \phi$, and resonant frequency Asked 2024 (3m)

2026 also asked when the impedance is minimum and when wattless current flows (answered below). NCERT §7.6.2–7.7, Eqs. 7.28–7.30.

1. With $v = v_m \sin \omega t$ and $i = i_m \sin(\omega t + \phi)$, the instantaneous power is

$$p = vi = v_m i_m \sin \omega t \sin(\omega t + \phi) = \frac{v_m i_m}{2} [\cos \phi - \cos(2\omega t + \phi)]$$

2. The second term averages to zero over a cycle. With $V = v_m/\sqrt{2}$ and $I = i_m/\sqrt{2}$ (rms values):

$$P = \frac{v_m i_m}{2} \cos \phi = \frac{v_m}{\sqrt{2}} \frac{i_m}{\sqrt{2}} \cos \phi$$

3. **Resonance:** $i_m = v_m/Z$ is largest when Z is smallest, i.e. when $X_C = X_L$:

$$\frac{1}{\omega_0 C} = \omega_0 L$$

$$P = VI \cos \phi = I^2 Z \cos \phi, \quad \omega_0 = \frac{1}{\sqrt{LC}}, \quad \nu_0 = \frac{1}{2\pi\sqrt{LC}}$$

Special cases. Pure R: $\cos \phi = 1$, maximum power. Pure L or pure C: $\phi = \pi/2$, $\cos \phi = 0$, so no power is used even though current flows: this is the **wattless current**. At resonance: $Z = R$ (minimum), $\cos \phi = 1$, $P = I^2 R$ (maximum).

Common mistake: writing $P = VI$ for an ac circuit. That is the apparent power; the real (average) power has the factor $\cos \phi$, the power factor.

7.4 AC voltage across an inductor: current lags by $\pi/2$, $X_L = \omega L$, no average power Asked 2024 (3m)

Asked as "show that an ideal inductor does not dissipate any power". NCERT §7.4, Eqs. 7.10–7.14.

1. Kirchhoff's loop rule with the back emf $-L di/dt$:

$$v - L \frac{di}{dt} = 0 \Rightarrow \frac{di}{dt} = \frac{v_m}{L} \sin \omega t$$

2. Integrating (the constant is zero, since the current oscillates symmetrically about zero):

$$i = -\frac{v_m}{\omega L} \cos \omega t = i_m \sin\left(\omega t - \frac{\pi}{2}\right), \quad i_m = \frac{v_m}{\omega L}$$

3. **Power:**

$$p_L = iv = -i_m v_m \cos \omega t \sin \omega t = -\frac{i_m v_m}{2} \sin 2\omega t$$

The average of $\sin 2\omega t$ over a cycle is zero.

$$X_L = \omega L, \quad i = i_m \sin\left(\omega t - \frac{\pi}{2}\right), \quad \bar{P}_L = 0$$

"When does an inductor act as a conductor?" (2024): for dc ($\omega = 0$), $X_L = 0$, so an ideal inductor is just a wire.

Also derived in NCERT, Chapter 7**7.5 RMS value of alternating current: $I = \frac{i_m}{\sqrt{2}} = 0.707 i_m$** In NCERT

2025 asked how the peak and rms values are related. NCERT §7.2, Eqs. 7.4–7.6.

1. Through a resistor, $i = i_m \sin \omega t$ and the power is $p = i^2 R = i_m^2 R \sin^2 \omega t$.

2. Average over a cycle: $\langle \sin^2 \omega t \rangle = \frac{1}{2} (1 - \langle \cos 2\omega t \rangle) = \frac{1}{2}$, so $\bar{p} = \frac{1}{2} i_m^2 R$.

3. The rms current I is the steady (dc) current that gives the same average power: $I^2 R = \frac{1}{2} i_m^2 R$.



$$I = \frac{i_m}{\sqrt{2}} = 0.707 i_m, \quad V = \frac{v_m}{\sqrt{2}} = 0.707 v_m$$

The average of a sinusoidal current over a full cycle is zero, which is why the rms value is used. "220 V mains" is an rms value; the peak is about 311 V.

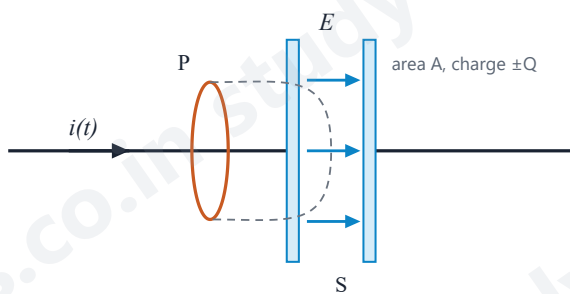
Transformer: the 2026-27 syllabus lists the transformer under Chapter 7. Its relations $\frac{V_s}{V_p} = \frac{N_s}{N_p}$ and, for an ideal transformer, $\frac{I_s}{I_p} = \frac{N_p}{N_s}$ follow from Faraday's law (NCERT §7.8). No board paper in 2022–2026 asked for this as a derivation.

8 Electromagnetic Waves

8.1 Displacement current $i_d = \epsilon_0 \frac{d\Phi_E}{dt}$ and the Ampere–Maxwell law

Asked 2025 (3m) · 2026 (3m)

Asked using a charging capacitor: "show that $i_d = \epsilon_0 d\Phi_E/dt$ " and "show that $i_c + i_d$ is the same everywhere in the circuit". NCERT §8.2, Eqs. 8.1–8.6.



A loop round the wire (solid) is the rim of two surfaces: a flat disc cut by the wire, and a "pot" (dashed) whose bottom S lies between the plates, where no conduction current flows.

1. Ampere's law $\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 i(t)$ on the flat disc gives $B(2\pi r) = \mu_0 i$. On the pot-shaped surface, no current passes through it, so it gives $B = 0$. A contradiction: the law is missing a term.

2. What does cross S is the electric field between the plates, $E = \frac{Q}{\epsilon_0 A}$. The flux through S:

$$\Phi_E = EA = \frac{Q}{\epsilon_0}$$

3. As the capacitor charges, $i = dQ/dt$:

$$\frac{d\Phi_E}{dt} = \frac{1}{\epsilon_0} \frac{dQ}{dt} \Rightarrow \epsilon_0 \frac{d\Phi_E}{dt} = i$$

4. So $\epsilon_0 d\Phi_E/dt$ is the missing term, the displacement current i_d . Outside the plates $i_c = i$, $i_d = 0$; between them $i_c = 0$, $i_d = i$. The total $i_c + i_d$ is the same through every surface, so the current is continuous round the circuit.

$$i_d = \epsilon_0 \frac{d\Phi_E}{dt}, \quad \oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 i_c + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$$

For a conductor across a **constant** voltage, $\mathbf{E}$ doesn't change, so $i_d = 0$ (2026). Kirchhoff's junction rule fails at a single plate for the conduction current alone, but holds once i_d is included (2025).

Common mistake: calling i_d a flow of charge. No charge moves between the plates; i_d is a changing electric field that produces a magnetic field just like a current.

Speed of EM waves: 2026 asked students to "show that $1/\sqrt{\epsilon_0 \mu_0}$ gives the speed of an EM wave". NCERT only states $c = 1/\sqrt{\mu_0 \epsilon_0}$ (Eq. 8.11), and the syllabus treats EM waves qualitatively. The expected answer is to substitute $\mu_0 = 4\pi \times 10^{-7}$ and $\epsilon_0 = 8.854 \times 10^{-12}$ and show the result is 3×10^8 m/s.

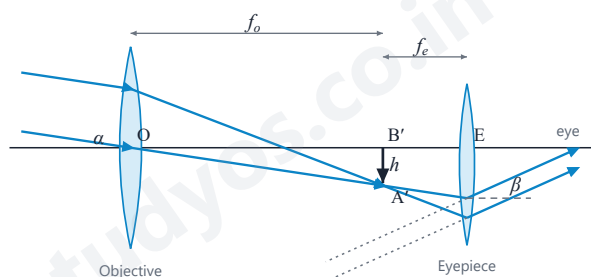


9 Ray Optics and Optical Instruments

9.1 Astronomical (refracting) telescope: magnifying power in normal adjustment

Asked 2022 (3m) · 2023 (5m) · 2026 (5m)

Diagram + expression also asked in 2025 (5m) and 2026 (2m, 3m). NCERT §9.7.2, Eq. 9.46.



Final image at infinity (normal adjustment).

1. Parallel rays from a distant object make angle α with the axis. The objective forms a real, inverted image A'B' of height h at its second focal point, i.e. at distance f_o .
2. In normal adjustment A'B' also lies at the first focal point of the eyepiece, so the final image is at infinity and the rays leave at angle β .
3. The object subtends α at the objective (it is so far away that this equals the angle at the eye):

$$\alpha \approx \tan \alpha = \frac{h}{f_o}$$

4. The final image subtends at the eye:

$$\beta \approx \tan \beta = \frac{h}{f_e}$$

5. Magnifying power is $m = \beta/\alpha$:

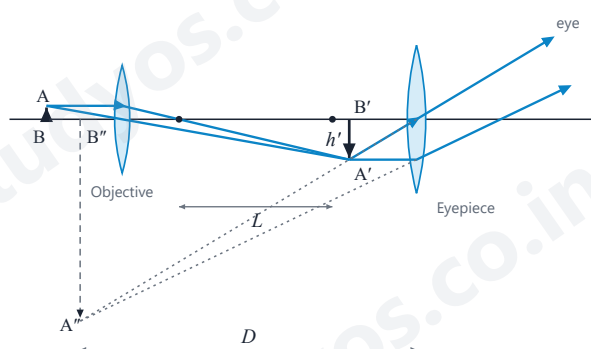
$$m = \frac{\beta}{\alpha} = \frac{h}{f_e} \cdot \frac{f_o}{h} = \frac{f_o}{f_e}, \quad L = f_o + f_e$$

Common mistake: using $1 + D/f_e$ here. That is the microscope near-point case. In normal adjustment the telescope's answer has no D in it.

9.2 Compound microscope: magnifying power (near point and infinity)

Asked 2024 (5m) · 2025 (5m) · 2026 (3m)

2024 and 2026 asked the near-point case, 2025 the infinity case. NCERT §9.7.1, Eqs. 9.43–9.45.



Final image A''B'' at the near point D . L = tube length, between the second focal point of the objective and the first focal point of the eyepiece.

1. **Objective.** It forms a real, inverted, magnified image A'B' near the eyepiece's focal point. From the similar triangles at the objective's second focal point,

$$\tan \beta = \frac{h}{f_o} = \frac{h'}{L} \Rightarrow m_o = \frac{h'}{h} = \frac{L}{f_o}$$

2. **Eyepiece** acts as a simple microscope (derivation 9.12) with A'B' as its object:

$$\text{final image at near point: } m_e = 1 + \frac{D}{f_e}$$

$$\text{final image at infinity: } m_e = \frac{D}{f_e}$$

3. Total magnification is the product, $m = m_o m_e$:

$$\text{Near point: } m = \frac{L}{f_o} \left(1 + \frac{D}{f_e} \right)$$

$$\text{Infinity: } m = \frac{L}{f_o} \cdot \frac{D}{f_e}$$



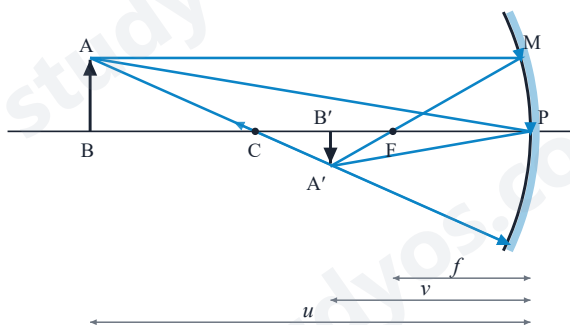
Another common way to write m_o is $v_o/|u_o|$ (image and object distances for the objective). It gives the same result when the first image is near the eyepiece's focus.

Common mistake: mixing up the two cases. Check whether the question says "least distance of distinct vision" (near point, $1 + D/f_e$) or "at infinity" (D/f_e).

9.3 Mirror formula $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$ and magnification $m = -\frac{v}{u}$

Asked 2023 (5m) · 2025 (3m)

Both times with a concave mirror forming a real image. NCERT §9.2.3, Eqs. 9.4–9.9.



Object AB beyond C; real, inverted image A'B' between C and F.

1. Right-angled triangles A'B'F and MPF are similar (for paraxial rays MP is a straight line perpendicular to the axis), and $PM = AB$:

$$\frac{B'A'}{BA} = \frac{B'F}{FP} \quad (9.4)$$

2. Since $\angle APB = \angle A'PB'$, triangles A'B'P and ABP are similar:

$$\frac{B'A'}{BA} = \frac{B'P}{BP} \quad (9.5)$$

3. Comparing, and using $B'F = B'P - FP$:

$$\frac{B'P - FP}{FP} = \frac{B'P}{BP}$$

4. Sign convention (distances measured against incident light are negative): $B'P = -v$, $FP = -f$, $BP = -u$:

$$\frac{-v + f}{-f} = \frac{-v}{-u} \Rightarrow \frac{v}{f} = 1 + \frac{v}{u}$$

5. Dividing by v :

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

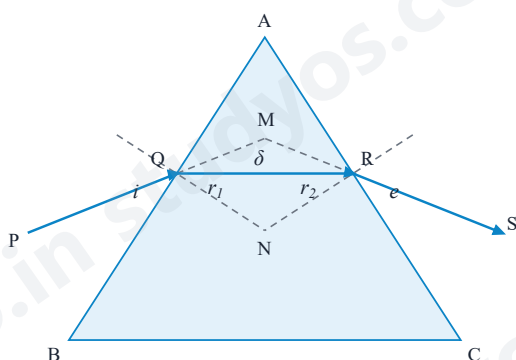
Magnification. From triangles A'B'P and ABP, $\frac{B'A'}{BA} = \frac{B'P}{BP}$. With signs, $\frac{-h'}{-h} = \frac{-v}{-u}$, so $m = \frac{h'}{h} = -\frac{v}{u}$.

Common mistake: putting signs into the similar-triangle ratios. Write the ratios with magnitudes first and apply the sign convention only in step 4.

9.4 Refraction through a prism: $r_1 + r_2 = A$ and $\delta = i + e - A$

Asked 2024 (5m)

Asked with the δ - i graph. NCERT §9.6, Eqs. 9.34–9.35.



QN and RN are normals to the two faces. δ is the angle between the incident ray PQ and the emergent ray RS.

1. In quadrilateral AQNR, the angles at Q and R are right angles, so

$$\angle A + \angle QNR = 180^\circ$$

2. In triangle QNR:

$$r_1 + r_2 + \angle QNR = 180^\circ$$

3. Comparing the two:

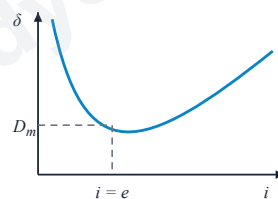
$$r_1 + r_2 = A \quad (9.34)$$

4. Total deviation is the sum of the deviations at the two faces:

$$\delta = (i - r_1) + (e - r_2) = i + e - (r_1 + r_2)$$



$$\delta = i + e - A$$



δ falls, reaches a minimum D_m when $i = e$, then rises. Every other value of δ occurs at two values of i (because i and e can be swapped).

Common mistake: using $r = A/2$ or $i = e$ here. Those hold only at minimum deviation (derivation 9.5). $\delta = i + e - A$ holds for any angle of incidence.

9.5 Refractive index of a prism from minimum deviation

Asked 2026 (5m)

Numericals on minimum deviation appeared in 2022, 2025 and 2026 too. NCERT §9.6, Eqs. 9.36–9.38. Use the figure in derivation 9.4.

1. At minimum deviation $\delta = D_m$, the ray passes symmetrically: $i = e$, which means $r_1 = r_2 = r$. The ray inside is parallel to the base.
2. From $r_1 + r_2 = A$:

$$2r = A \Rightarrow r = \frac{A}{2} \quad (9.36)$$

3. From $\delta = i + e - A$:

$$D_m = 2i - A \Rightarrow i = \frac{A + D_m}{2} \quad (9.37)$$

4. By Snell's law at the first face, $n_{21} = \sin i / \sin r$:

$$n_{21} = \frac{n_2}{n_1} = \frac{\sin [(A + D_m)/2]}{\sin [A/2]}$$

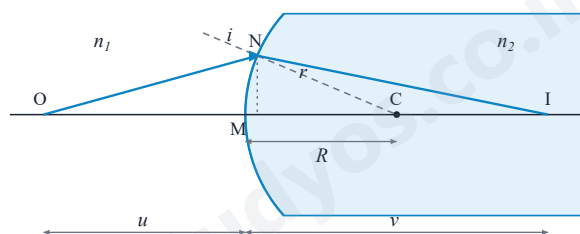
Thin prism (small A , so small D_m): $\sin \theta \approx \theta$ gives $n_{21} \approx \frac{(A+D_m)/2}{A/2}$, so $D_m = (n_{21} - 1)A$. Thin prisms deviate light only a little.

Common mistake: writing $\sin(A + D_m) / \sin A$ without the halves. Both angles are halved.

9.6 Refraction at a convex spherical surface: $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$

Asked 2026 (5m)

Numericals using this relation appeared in 2025 and 2026. NCERT §9.5.1, Eqs. 9.13–9.16.



Small aperture: NM is taken equal to the perpendicular from N to the axis. NC is the normal at N.

1. For small angles (paraxial rays), with $\tan \theta \approx \theta$:

$$\begin{aligned} \angle NOM &= \frac{MN}{OM}, & \angle NCM &= \frac{MN}{MC} \\ \angle NIM &= \frac{MN}{MI} \end{aligned}$$

2. i is the exterior angle of $\triangle NOC$:

$$i = \angle NOM + \angle NCM = \frac{MN}{OM} + \frac{MN}{MC} \quad (9.13)$$

3. Similarly, from $\triangle NCI$:

$$r = \angle NCM - \angle NIM = \frac{MN}{MC} - \frac{MN}{MI} \quad (9.14)$$

4. Snell's law $n_1 \sin i = n_2 \sin r$ becomes $n_1 i = n_2 r$ for small angles. Substituting:

$$\frac{n_1}{OM} + \frac{n_2}{MI} = \frac{n_2 - n_1}{MC} \quad (9.15)$$

5. Sign convention: $OM = -u$, $MI = +v$, $MC = +R$:



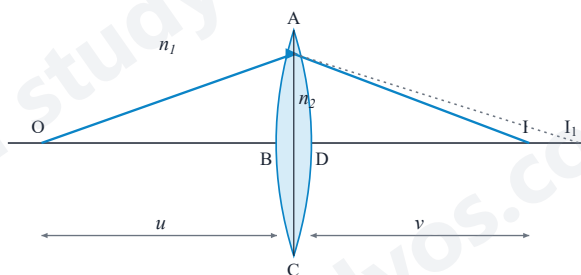
$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$$

Common mistake: skipping the small-angle step. The derivation only works because $\tan \theta \approx \theta$ and $\sin \theta \approx \theta$ for paraxial rays, so say so.

9.7 Lens maker's formula: $\frac{1}{f} = (n_{21} - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$

Asked 2026 (5m)

Asked as "using the relation for refraction at a curved spherical surface", i.e. derivation 9.6 applied twice. NCERT §9.5.2, Eqs. 9.17–9.21.



Surface ABC alone would form the image I_1 . I_1 acts as a virtual object for surface ADC, which forms the final image I .

1. Apply Eq. 9.15 to the first surface ABC (centre C_1):

$$\frac{n_1}{OB} + \frac{n_2}{BI_1} = \frac{n_2 - n_1}{BC_1} \quad (9.17)$$

2. For the second surface ADC (centre C_2), light goes from n_2 back to n_1 , and I_1 is a virtual object:

$$-\frac{n_2}{DI_1} + \frac{n_1}{DI} = \frac{n_1 - n_2}{DC_2} \quad (9.18)$$

3. Thin lens: $BI_1 = DI_1$. Adding (9.17) and (9.18):

$$\frac{n_1}{OB} + \frac{n_1}{DI} = (n_2 - n_1) \left(\frac{1}{BC_1} + \frac{1}{DC_2} \right) \quad (9.19)$$

4. Object at infinity: $OB \rightarrow \infty$ and $DI = f$:

$$\frac{n_1}{f} = (n_2 - n_1) \left(\frac{1}{BC_1} + \frac{1}{DC_2} \right) \quad (9.20)$$

5. Sign convention: $BC_1 = +R_1$, $DC_2 = -R_2$. Dividing by n_1 and writing $n_{21} = n_2/n_1$:

$$\frac{1}{f} = (n_{21} - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$$

Also true for a concave lens: there R_1 is negative and R_2 positive, so f comes out negative.

Common mistake: writing $+\frac{1}{R_2}$. The minus sign comes from $DC_2 = -R_2$; for a double-convex lens R_2 is itself negative, so both terms end up adding.

9.8 Thin lens formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ and $m = \frac{v}{u}$

In NCERT · continues derivation 9.7

NCERT §9.5.2, Eqs. 9.22–9.24. Not asked on its own in 2022–2026, but it is the last step of the lens maker's derivation.

1. From Eqs. 9.19 and 9.20, the right-hand sides are equal:

$$\frac{n_1}{OB} + \frac{n_1}{DI} = \frac{n_1}{f} \quad (9.22)$$

2. For a thin lens, B and D are both close to the optical centre. Sign convention: $BO = -u$, $DI = +v$:

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

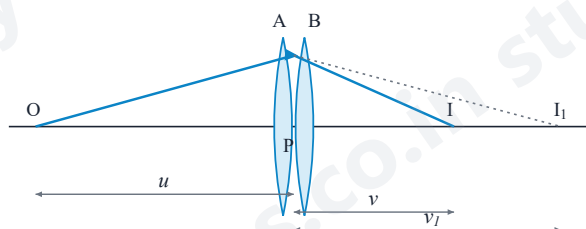
Magnification. Proceeding as for the mirror, $m = \frac{h'}{h} = \frac{v}{u}$. It is positive for an erect (virtual) image and negative for an inverted (real) image.



9.9 Two thin lenses in contact: $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$

Asked 2026 (2m)

Asked as "prove that $f = \frac{f_1 f_2}{f_1 + f_2}$ ". Numericals in 2025 and 2026 too. NCERT §9.5.4, Eqs. 9.27–9.33.



Lens A alone would form I_1 ; this acts as a virtual object for lens B, which forms I. Optical centres coincide at P.

1. Lens A (focal length f_1) forms I_1 :

$$\frac{1}{v_1} - \frac{1}{u} = \frac{1}{f_1} \quad (9.27)$$

2. I_1 is the object for lens B (focal length f_2):

$$\frac{1}{v} - \frac{1}{v_1} = \frac{1}{f_2} \quad (9.28)$$

3. Adding:

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f_1} + \frac{1}{f_2} \quad (9.29)$$

4. For the equivalent single lens of focal length f , $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$. Comparing:

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} \Rightarrow f = \frac{f_1 f_2}{f_1 + f_2}, \quad P = P_1 + P_2$$

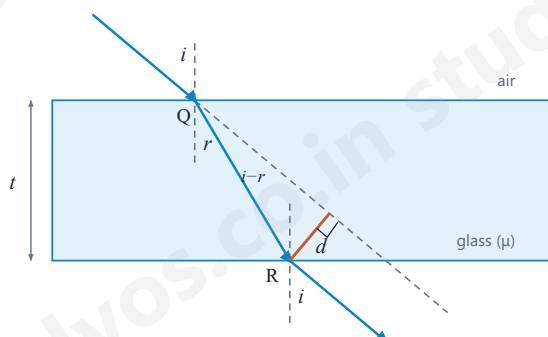
For any number of lenses in contact, $P = P_1 + P_2 + P_3 + \dots$ (algebraic sum) and $m = m_1 m_2 m_3 \dots$

Common mistake: adding focal lengths. Powers add; focal lengths don't. Keep the sign of each lens (concave = negative).

9.10 Lateral shift through a parallel-sided glass slab

Asked 2025 (3m) · Not in NCERT

NCERT shows the shift in Fig. 9.9 but does not derive it. CBSE asked for the expression in 2025, so learn it from here.



The dashed line is the incident ray continued without refraction. d is the perpendicular distance between it and the emergent ray.

1. The ray enters at Q at angle i , refracts at angle r , and leaves the bottom face at R. At R it refracts back into air at angle i , so the emergent ray is parallel to the incident ray.

2. Length of the path inside the slab of thickness t :

$$QR = \frac{t}{\cos r}$$

3. The angle between QR and the undeviated (dashed) path is $i - r$. The lateral shift d is the perpendicular from R onto that path:

$$d = QR \sin(i - r)$$

$$d = \frac{t \sin(i - r)}{\cos r}$$

When is it minimum? At normal incidence ($i = 0$, so $r = 0$) the shift is zero. It grows with the thickness t and the angle of incidence i .

Common mistake: using t as the path length. The path inside is $t / \cos r$, which is longer than t .

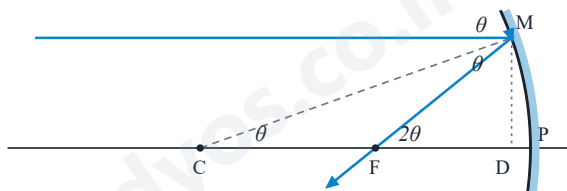


Also derived in NCERT, Chapter 9

9.11 Focal length of a spherical mirror: $f = R/2$

In NCERT

NCERT §9.2.2, Eqs. 9.1–9.3.



A ray parallel to the axis strikes the mirror at M. CM is the normal; MD is perpendicular to the axis.

1. With angle of incidence θ : $\angle MCP = \theta$ and $\angle MFP = 2\theta$.

$$2. \quad \tan \theta = \frac{MD}{CD}, \quad \tan 2\theta = \frac{MD}{FD} \quad (9.1)$$

3. For paraxial rays $\tan \theta \approx \theta$ and $\tan 2\theta \approx 2\theta$, so

$$\frac{MD}{FD} = 2 \frac{MD}{CD} \Rightarrow FD = \frac{CD}{2} \quad (9.2)$$

4. For small θ , D is very close to P, so $FD = f$ and $CD = R$:

$$f = \frac{R}{2}$$

9.12 Simple microscope: magnification at the near point and at infinity

In NCERT

NCERT §9.7.1, Eqs. 9.39–9.42 (see Fig. 9.23 in the book). Used inside derivation 9.2 for the eyepiece.

Image at the near point ($v = -D$). Using the lens formula,

$$m = \frac{v}{u} = v \left(\frac{1}{v} - \frac{1}{f} \right) = 1 - \frac{v}{f} \Rightarrow m = 1 + \frac{D}{f}$$

Image at infinity (object at $u = -f$). Without the lens, the largest angle the object can subtend while still being seen clearly is at the near point: $\theta_o \approx \tan \theta_o = \frac{h}{D}$. With the object at the focus, the image subtends $\theta_i = \frac{h}{f}$. So the angular magnification is

$$m = \frac{\theta_i}{\theta_o} = \frac{D}{f}$$

$$m_{\text{near point}} = 1 + \frac{D}{f}, \quad m_{\infty} = \frac{D}{f}$$

The infinity case gives one less magnification, but viewing is more relaxed. With $D = 25$ cm, a magnification of 6 needs $f = 5$ cm.

9.13 Critical angle: $\sin i_c = n_{21}$, so $n = 1/\sin i_c$ for a medium in air

In NCERT

NCERT §9.4, Eq. 9.12. Asked in 2026 as "state the two conditions for total internal reflection" rather than as a derivation.

1. Light goes from a denser medium 1 to a rarer medium 2. The critical angle i_c is the angle of incidence for which the angle of refraction is 90° .
2. Snell's law, $\sin i / \sin r = n_{21}$, with $r = 90^\circ$:

$$\sin i_c = n_{21} \quad \Rightarrow \quad n_{12} = \frac{1}{\sin i_c}$$

Conditions for TIR: (i) light travels from a denser to a rarer medium; (ii) the angle of incidence is greater than i_c .

9.14 Power of a lens: $P = 1/f$

In NCERT

NCERT §9.5.3, Eq. 9.25.

Power is the tangent of the angle δ through which the lens bends a ray parallel to the axis at unit distance ($h = 1$) from the optical centre: $\tan \delta = \frac{h}{f}$. With $h = 1$ and small δ , $\delta = \frac{1}{f}$.

$$P = \frac{1}{f} \quad (f \text{ in metres; unit diopetre, } 1 \text{ D} = 1 \text{ m}^{-1})$$



Positive for a converging (convex) lens, negative for a diverging (concave) lens. +2.5 D is a convex lens of focal length +40 cm.

10 Wave Optics

10.1 Resultant intensity of two coherent waves: $I = 4I_0 \cos^2(\phi/2)$

Asked 2024 (2m, 5m) · 2025 (5m) · 2026 (2m)

The most-asked Wave Optics derivation: four 2024 papers asked it. 2026 asked "prove that the maxima and minima are $4I$ and 0 ". NCERT §10.4, Eq. 10.11.

1. Displacements at a point from two coherent sources of equal amplitude a , with phase difference ϕ :

$$y_1 = a \cos \omega t, \quad y_2 = a \cos(\omega t + \phi)$$

2. Superposition, using $\cos A + \cos B = 2 \cos \frac{A+B}{2} \cos \frac{A-B}{2}$:

$$y = y_1 + y_2 = a[\cos \omega t + \cos(\omega t + \phi)] = 2a \cos \frac{\phi}{2} \cos \left(\omega t + \frac{\phi}{2} \right)$$

3. The resultant amplitude is $2a \cos(\phi/2)$. Intensity is proportional to amplitude squared, and each source alone gives $I_0 \propto a^2$:

$$I = 4I_0 \cos^2 \frac{\phi}{2}$$

Maximum $I = 4I_0$ when $\phi = 0, \pm 2\pi, \pm 4\pi, \dots$ **Minimum** $I = 0$ when $\phi = \pm \pi, \pm 3\pi, \dots$ **Incoherent sources:** ϕ changes rapidly, $\langle \cos^2(\phi/2) \rangle = \frac{1}{2}$, so $I = 2I_0$ everywhere and no pattern is seen.

Common mistake: writing $I_{\max} = 2I_0$. Amplitudes add ($2a$), and intensity goes as amplitude squared, so the maximum is $4I_0$. Energy is conserved because the minima are dark.

10.2 Conditions for constructive and destructive interference in terms of path difference

Asked 2025 (5m)

NCERT §10.4, Eqs. 10.9–10.10.

1. A path difference of λ corresponds to a phase difference of 2π , so phase difference $\phi = \frac{2\pi}{\lambda} \times \text{path difference}$.
2. **Constructive:** if $S_1P \sim S_2P = n\lambda$, then $\phi = 2n\pi$ and $y_2 = a \cos(\omega t - 2n\pi) = a \cos \omega t$. The waves arrive in phase: $y = 2a \cos \omega t$, intensity $4I_0$.
3. **Destructive:** if $S_1P \sim S_2P = (n + \frac{1}{2})\lambda$, then $\phi = (2n + 1)\pi$ and $y_2 = -a \cos \omega t$. The waves cancel: intensity 0.

$$\text{Constructive: } S_1P \sim S_2P = n\lambda \quad \text{Destructive: } S_1P \sim S_2P = (n + \frac{1}{2})\lambda \quad (n = 0, 1, 2, \dots)$$

These hold for sources vibrating in phase, and assume S_1P, S_2P are much larger than the slit separation so both amplitudes are nearly equal.

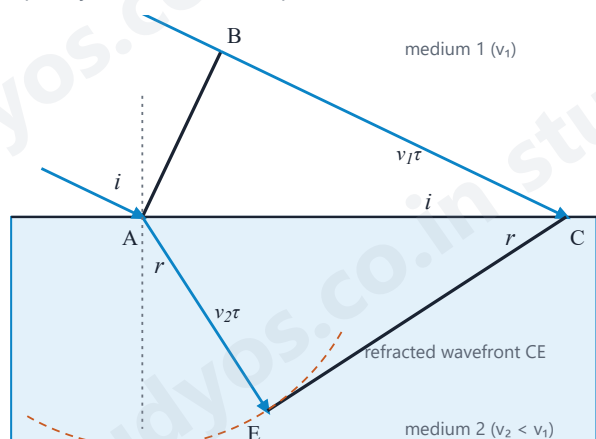
10.3 Huygens' principle: proof of Snell's law of refraction

Asked 2025 (5m)

Asked as "explain the wavefront propagating in air at a plane interface between two media". The syllabus names this proof



explicitly. NCERT §10.3.1, Eqs. 10.1–10.7.



AB is the incident wavefront, CE the refracted one. In time τ , B reaches C while the wavelet from A grows to radius $v_2\tau$.

1. Plane wavefront AB meets the interface at A. Let τ be the time for B to reach C: $BC = v_1\tau$.
2. In the same time, the secondary wavelet from A spreads into medium 2 as a sphere of radius $AE = v_2\tau$. The tangent plane CE from C to this sphere is the refracted wavefront.
3. From right triangles ABC and AEC (angle of incidence i at A in $\triangle ABC$, angle of refraction r at C in $\triangle AEC$):

$$\sin i = \frac{BC}{AC} = \frac{v_1\tau}{AC}, \quad \sin r = \frac{AE}{AC} = \frac{v_2\tau}{AC}$$

4. Dividing, and using $n_1 = c/v_1$, $n_2 = c/v_2$:

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} \Rightarrow n_1 \sin i = n_2 \sin r$$

If $r < i$ then $v_2 < v_1$: light slows down in a denser medium. (The corpuscular model predicted the opposite; experiment sides with waves.) The frequency stays the same, so $v_1/\lambda_1 = v_2/\lambda_2$.

Common mistake: drawing the refracted wavefront from A. It is the tangent drawn from C to the wavelet centred at A.

Also derived in NCERT, Chapter 10

10.4 Huygens' principle: proof of the law of reflection

In NCERT

NCERT §10.3.3. Listed by name in the 2026-27 syllabus.

1. Plane wavefront AB meets reflecting surface MN at A, at angle i . In time τ , B travels to C: $BC = v\tau$.
2. In the same time the wavelet from A, in the same medium, grows to radius $AE = v\tau$. The tangent CE from C is the reflected wavefront.
3. Right triangles BAC and ECA share the hypotenuse AC and have $BC = AE$, so they are congruent. Hence the angle the incident wavefront makes with the surface equals the angle the reflected wavefront makes with it:

$$\angle i = \angle r$$

Young's double-slit fringe width is "no derivation, final expression only" in the CBSE 2026-27 syllabus: $\beta = \frac{\lambda D}{d}$.

Single-slit diffraction and the width of the central maximum are "qualitative treatment only" (central maximum angular width $2\lambda/a$). 2022 asked for the first maximum of the single slit, but that was under the older syllabus.

11 Dual Nature of Radiation and Matter

11.1 de Broglie wavelength of a charged particle accelerated through a potential difference

Asked 2026 (3m)

NCERT §11.8, Eq. 11.5 (applied to an accelerated particle).

1. A particle of charge q and mass m , starting from rest, is accelerated through potential difference V . Its kinetic energy is $K = qV$.



2. Momentum from kinetic energy: $K = \frac{p^2}{2m} \Rightarrow p = \sqrt{2mK} = \sqrt{2mqV}$.

3. de Broglie relation $\lambda = h/p$:

$$\lambda = \frac{h}{\sqrt{2mqV}} \quad \text{electron: } \lambda = \frac{1.227}{\sqrt{V}} \text{ nm}$$

The electron value uses $h = 6.63 \times 10^{-34}$ J s, $m = 9.11 \times 10^{-31}$ kg and $q = e$. For a given V , heavier particles have shorter wavelengths.

Common mistake: writing $p = mv$ with v from $\frac{1}{2}mv^2 = qV$ and then forgetting the square root. Go through $p = \sqrt{2mK}$ directly.

11.2 The de Broglie wavelength of a photon equals the wavelength of the radiation

Asked 2026 (3m)

NCERT §11.8, Eqs. 11.6–11.7.

1. The de Broglie relation for any particle of momentum p : $\lambda = \frac{h}{p}$.
2. A photon of frequency ν has energy $E = h\nu$ and momentum $p = \frac{E}{c} = \frac{h\nu}{c}$.
3. Substituting:

$$\lambda = \frac{h}{p} = \frac{h}{h\nu/c} = \frac{c}{\nu}$$

c/ν is exactly the wavelength of the electromagnetic radiation, so the de Broglie relation is consistent with what we already know about light.

Also in NCERT, Chapter 11

11.3 Einstein's photoelectric equation $K_{\max} = h\nu - \phi_0$, threshold frequency and stopping potential

In NCERT

NCERT §11.6, Eqs. 11.2–11.4. 2022 and 2023 asked numericals and graph questions built on it.

1. Radiation comes in quanta of energy $h\nu$. An electron absorbs one quantum; it needs at least the work function ϕ_0 to escape. The rest becomes kinetic energy, at most:

$$K_{\max} = h\nu - \phi_0$$

2. **Threshold:** emission needs $K_{\max} \geq 0$, i.e. $\nu \geq \nu_0 = \phi_0/h$. Below ν_0 there is no emission, however intense the light.

3. **Stopping potential:** the fastest electrons are just stopped when $eV_0 = K_{\max}$:

$$eV_0 = h\nu - \phi_0 \Rightarrow V_0 = \frac{h}{e}\nu - \frac{\phi_0}{e}$$

$$K_{\max} = h\nu - \phi_0 = h(\nu - \nu_0), \quad V_0 = \frac{h}{e}\nu - \frac{\phi_0}{e}$$

A graph of V_0 against ν is a straight line with slope h/e and intercept ν_0 on the frequency axis. Intensity changes the number of photoelectrons, not $K_{\max}$.



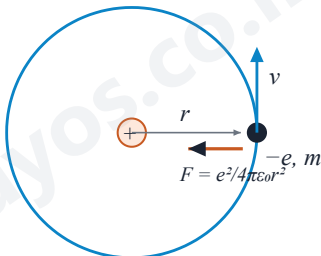
12 Atoms

12.1 Bohr model: radius of the n th orbit, $r_n \propto n^2$

Asked 2024 (3m) · 2025 (3m)

Asked in three 2024 and three 2025 papers, usually with "state Bohr's postulates". 2024 also asked "show the orbits are not equally spaced". NCERT §12.2.2 and §12.4, Eqs. 12.2, 12.5, 12.7.

proton (+e)



The Coulomb attraction of the nucleus provides the centripetal force.

1. **Force balance** (Coulomb force = centripetal force):

$$\frac{1}{4\pi\epsilon_0} \frac{e^2}{r^2} = \frac{mv^2}{r} \Rightarrow mv^2 = \frac{e^2}{4\pi\epsilon_0 r}$$

2. **Bohr's second postulate** (quantised angular momentum):

$$mvr = \frac{nh}{2\pi} \Rightarrow v = \frac{nh}{2\pi mr}$$

3. Substituting v into step 1:

$$m \frac{n^2 h^2}{4\pi^2 m^2 r^2} = \frac{e^2}{4\pi\epsilon_0 r} \Rightarrow r = \frac{n^2 h^2 \epsilon_0}{\pi m e^2}$$

$$r_n = \left(\frac{n^2}{m}\right) \left(\frac{h}{2\pi}\right)^2 \frac{4\pi\epsilon_0}{e^2} = \frac{n^2 h^2 \epsilon_0}{\pi m e^2} \propto n^2$$

For $n = 1$: Bohr radius $a_0 = \frac{h^2 \epsilon_0}{\pi m e^2} = 5.29 \times 10^{-11}$ m. Since $r_n = n^2 a_0$, the gaps $r_{n+1} - r_n = (2n + 1)a_0$ grow with n : the orbits are not equally spaced. Also, from step 2, $v_n \propto 1/n$.

Common mistake: stating $r \propto n$. The angular-momentum condition gives $v \propto 1/n$, and together with the force balance this makes $r \propto n^2$.

12.2 Total energy of the electron, $E_n = -\frac{13.6}{n^2}$ eV

Asked 2025 (3m) · 2026 (3m)

2025 asked for E in terms of r and the meaning of the minus sign, and "prove $E \propto 1/n^2$ ". 2026 asked "show the levels get closer as n grows". NCERT §12.2.2, §12.4, Eqs. 12.3–12.10.

1. Kinetic energy, from the force balance $mv^2 = \frac{e^2}{4\pi\epsilon_0 r}$:

$$K = \frac{1}{2}mv^2 = \frac{e^2}{8\pi\epsilon_0 r}$$

2. Potential energy of the electron in the proton's field:

$$U = -\frac{e^2}{4\pi\epsilon_0 r}$$

3. Total energy in terms of r :

$$E = K + U = -\frac{e^2}{8\pi\epsilon_0 r}$$

4. Substitute $r_n = \frac{n^2 h^2 \epsilon_0}{\pi m e^2}$ (derivation 12.1):

$$E_n = -\frac{me^4}{8n^2\epsilon_0^2 h^2} = -\frac{2.18 \times 10^{-18}}{n^2} \text{ J} = -\frac{13.6}{n^2} \text{ eV}$$

Minus sign: the electron is bound to the nucleus; 13.6 eV must be supplied to free it from the ground state (ionisation energy). Note $K = -E$ and $U = 2E$.

Levels get closer as n grows: $E_{n+1} - E_n = 13.6 \left[\frac{1}{n^2} - \frac{1}{(n+1)^2} \right] = \frac{13.6(2n+1)}{n^2(n+1)^2}$ eV, which goes as $2/n^3 \rightarrow 0$ for large n .



Common mistake: dropping the factor 2 in $K = e^2/8\pi\epsilon_0 r$. It comes from the $\frac{1}{2}$ in $\frac{1}{2}mv^2$.

12.3 Time period of the electron in the n th orbit, $T \propto n^3$

Asked 2025 (2m) · Not in NCERT

Follows from derivation 12.1. 2024 asked the related result: for large n , the frequency of light from an $n \rightarrow n-1$ jump goes as $1/n^3$ (Bohr's correspondence principle).

1. From derivation 12.1: $r_n \propto n^2$ and $v_n = \frac{nh}{2\pi m r_n} \propto \frac{n}{n^2} = \frac{1}{n}$.

2. Time for one revolution:

$$T_n = \frac{2\pi r_n}{v_n} \propto \frac{n^2}{1/n} = n^3$$

$$T_n \propto n^3, \quad \text{orbital frequency } \nu_n = \frac{1}{T_n} \propto \frac{1}{n^3}$$

2024 version: the photon frequency for $n \rightarrow n-1$ is $\nu = \frac{E_n - E_{n-1}}{h} = \frac{13.6 \text{ eV}}{h} \cdot \frac{2n-1}{n^2(n-1)^2} \approx \frac{13.6 \text{ eV}}{h} \cdot \frac{2}{n^3}$ for large n , which matches the classical orbital frequency.

12.4 Distance of closest approach of an alpha particle

Asked 2025 (2m)

NCERT Example 12.2.

- The alpha particle (charge $2e$) heads straight at a nucleus (charge Ze) with kinetic energy K . Mechanical energy is conserved.
- At the distance of closest approach d it stops momentarily: all of K has become electric potential energy:

$$K = \frac{1}{4\pi\epsilon_0} \frac{(2e)(Ze)}{d}$$

$$d = \frac{2Ze^2}{4\pi\epsilon_0 K}$$

For a 7.7 MeV alpha particle on gold ($Z = 79$), $d \approx 30 \text{ fm}$. This gives an upper limit on the size of the nucleus.

Hydrogen line spectra are "qualitative treatment only" in the 2026-27 syllabus. For transitions, use $h\nu = E_{n_i} - E_{n_f}$; wavelength relations such as $\frac{1}{\lambda_3} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$ (2022) follow from adding the energy differences.

13 Nuclei

13.1 Nuclear density is the same for all nuclei

Asked 2023 (3m, 2m) · 2024 (3m) · 2026 (3m, 2m)

Asked in seven papers across three years. NCERT §13.3 states the result (Eq. 13.5); the steps below fill it in.

- Experimentally, a nucleus of mass number A has radius $R = R_0 A^{1/3}$, with $R_0 = 1.2 \times 10^{-15} \text{ m}$.
- Volume: $V = \frac{4}{3}\pi R^3 = \frac{4}{3}\pi R_0^3 A$.
- Mass: each nucleon has mass about m ($1 \text{ u} \approx 1.66 \times 10^{-27} \text{ kg}$), so $M = mA$.
- Density:

$$\rho = \frac{M}{V} = \frac{mA}{\frac{4}{3}\pi R_0^3 A}$$

A cancels.

$$\rho = \frac{3m}{4\pi R_0^3} \approx 2.3 \times 10^{17} \text{ kg m}^{-3}, \text{ independent of } A$$



Nuclei are like drops of a liquid of constant density. Nuclear density is about 10^{14} times that of water, because an atom is mostly empty space while the nucleus is packed with nucleons.

Common mistake: using $R \propto A$. The radius goes as $A^{1/3}$, so the volume, not the radius, is proportional to A .

13.2 Energy equivalent of one atomic mass unit: $1 \text{ u} = 931.5 \text{ MeV}$

Asked 2026 (3m)

Asked as "derive the relation between atomic mass unit (u) and electron volt (eV)". NCERT Example 13.3.

1. $1 \text{ u} = 1.6605 \times 10^{-27} \text{ kg}$. Einstein's relation $E = mc^2$:

$$E = 1.6605 \times 10^{-27} \times (2.9979 \times 10^8)^2 = 1.4924 \times 10^{-10} \text{ J}$$

2. Convert using $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$:

$$E = \frac{1.4924 \times 10^{-10}}{1.602 \times 10^{-19}} \text{ eV} = 0.9315 \times 10^9 \text{ eV}$$

$$1 \text{ u} = 931.5 \text{ MeV}/c^2$$

Use this to turn a mass defect into binding energy: $E_b = \Delta M c^2$, with $\Delta M = [Zm_p + (A - Z)m_n] - M$. For ^{16}O , $\Delta M = 0.13691 \text{ u}$, so $E_b = 127.5 \text{ MeV}$.

Also asked: 2023 and 2026 asked for the graph of nucleon-pair potential energy against separation, and to show from it that the nuclear force is attractive for $r > r_0$ and repulsive for $r < r_0$. That is a graph-reading answer rather than a derivation: the force is $F = -dU/dr$, so where the curve slopes upward ($r > r_0$) the force is attractive, and where it slopes downward ($r < r_0$) it is repulsive.

14 Semiconductor Electronics

Semiconductor Electronics has no derivations in the CBSE 2026-27 syllabus, and no board paper in 2022–2026 asked for one. Questions here are about energy bands, p- and n-type doping, the p-n junction, diode I–V characteristics and the rectifier, so revise those with labelled diagrams and graphs instead.

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