



Physics Made Simple

Easy notes + solved problems for every chapter

CHSE Odisha · Class XI & XII · Syllabus 2023–24

28 chapters

230 solved problems

Detailed theory

56 long answers

30 diagrams

224 MCQs

1-mark Q&A

How to use these notes

💡 **Coloured box** – idea in simple words 📖 **More theory** – derivations, facts & applications

📌 **Yellow box** – formulas to remember

📚 **Theory in detail** – concepts in paragraphs 📐 **Diagrams** ⚡ **Quick 1-mark questions**

🎯 **Remember in one line** – quick revision ✅ **MCQs** with answer key

📝 **Long answer questions** – 5-mark derivations and explanations with full answers

✍️ **Solved problems** – read the steps, then cover them and try yourself ✓ green
– final answer

Contents & Marks Plan

Class XI

1	Units and Measurements
2	Motion in a Straight Line
3	Motion in a Plane
4	Laws of Motion
5	Work, Energy and Power
6	System of Particles and Rotational Motion
7	Gravitation
8	Mechanical Properties of Solids
9	Mechanical Properties of Fluids
10	Thermal Properties of Matter
11	Thermodynamics
12	Kinetic Theory of Gases
13	Oscillations
14	Waves

Units (Class XI theory, 70 marks)	Marks
I-IV: Measurement, Kinematics, Laws of Motion, Work-Energy	23
V-VI: Rotational Motion, Gravitation	17
VII-IX: Bulk Matter, Thermodynamics, Kinetic Theory	20
X: Oscillations and Waves	10

Class XII

1	Electric Charges and Fields
2	Electrostatic Potential and Capacitance
3	Current Electricity
4	Moving Charges and Magnetism
5	Magnetism and Matter
6	Electromagnetic Induction
7	Alternating Current
8	Electromagnetic Waves
9	Ray Optics and Optical Instruments
10	Wave Optics
11	Dual Nature of Radiation and Matter
12	Atoms
13	Nuclei
14	Semiconductor Electronics

Units (Class XII theory, 70 marks)	Marks
I-II: Electrostatics, Current Electricity	16
III-IV: Magnetism, EMI & AC	17
V-VI: EM Waves, Optics	18
VII-VIII: Dual Nature, Atoms & Nuclei	12
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Practical exam: 30 marks in each class (experiment 15, record 4, conceptual question 5, viva 6).



Class XII

Electricity • Magnetism • Optics • Modern Physics • Electronics

01 Electric Charges and Fields

Class XII · Unit I

In simple words

- **Charge** is of two types: + and -. Like charges repel, unlike attract. Charge is **conserved** and **quantised** ($q = ne$, $e = 1.6 \times 10^{-19}$ C).
- **Coulomb's law**: force between two point charges $\propto q_1q_2/r^2$. For many charges, add forces as vectors (superposition).
- **Electric field** E = force per unit positive charge. Field lines start on + and end on -; they never cross.
- **Electric dipole**: two equal and opposite charges; dipole moment $p = q \times 2a$. In a uniform field it feels a torque $\tau = pE \sin\theta$.
- **Gauss's theorem**: total flux through a closed surface = $q_{\text{enclosed}}/\epsilon_0$. Field inside a charged shell is zero.

Remember in one line

- | | |
|---|---|
| 1 Like charges repel, unlike charges attract. | 2 Charge is conserved and comes in multiples of e . |
| 3 Coulomb force $\propto q_1q_2/r^2$. | 4 Field lines go from + to - and never cross. |
| 5 Total flux through a closed surface = q/ϵ_0 (Gauss). | 6 Field inside a charged hollow conductor is zero. |

Theory in detail

What is charge?

Charge is a basic property of matter, like mass, due to which it feels electric force. Protons carry positive charge and electrons negative charge of the same size, $e = 1.6 \times 10^{-19}$ C. A body becomes charged by gaining or losing electrons — never protons. So a negatively charged body has extra electrons and its mass increases very slightly.

Conductors and insulators

In **conductors** (metals, human body, earth) some electrons are free to move, so charge spreads over the body. In **insulators** (glass, plastic, rubber) charges cannot move freely and stay where they are placed. **Earthing** connects a body to the ground so extra charge flows away — used for safety in electric appliances.

Electric field idea

A charge changes the space around it; another charge placed there feels a force. This region of influence is the **electric field**. $E = F/q_0$, unit N/C or V/m. The test charge q_0 must be very small so that it does not disturb the source charges. The field exists even if no test charge is placed.

Superposition principle

When several charges act on a charge, the force due to each is calculated separately (as if others were absent) and all forces are added as vectors. The presence of other charges does not change the force between any two. The same principle applies to electric fields: $E = E_1 + E_2 + \dots$

Quantisation and conservation

Charge always comes in whole-number multiples of e : $q = \pm ne$. We can never have $1.5e$ of free charge. **Conservation:** charge can neither be created nor destroyed, only transferred. In any process (even in nuclear reactions or pair production of an electron and a positron), total charge stays the same.

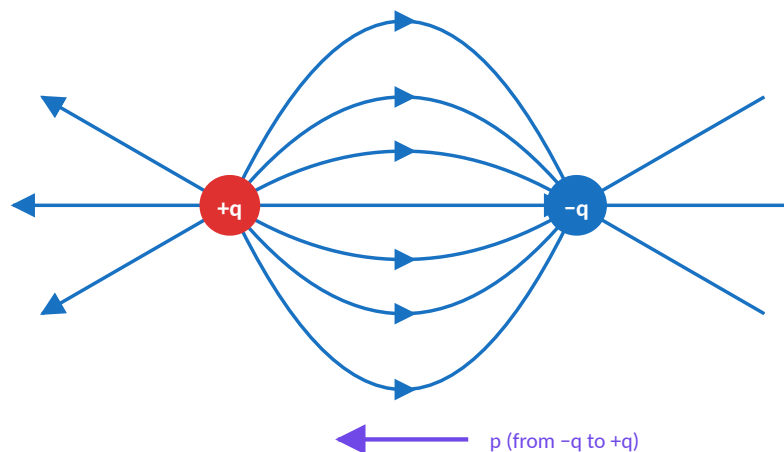


 Fig. 1.1: Electric field lines of an electric dipole: they start on $+q$ and end on $-q$

More theory - explained

- **Ways of charging:** by friction (rubbing), by conduction (touching) and by induction (bringing near, without touching). Charge is **additive**: total = algebraic sum.
- **Coulomb's law in a medium:** $F = F_0/K$, where $K = \epsilon/\epsilon_0$ is the dielectric constant (water $K \approx 80$).
- **Electric vs gravitational force:** between an electron and a proton, the electric force is about 10^{39} times stronger.
- **Continuous charge:** linear density $\lambda = q/L$ (C/m), surface density $\sigma = q/A$ (C/m²), volume density $\rho = q/V$ (C/m³).
- **Properties of field lines:** start on $+$, end on $-$; never cross (else two directions at one point); crowded where field is strong; meet a conductor at 90° ; never form closed loops.
- **Dipole field** ($r \gg a$): on axis $E = 2kp/r^3$ (along p); on equatorial line $E = kp/r^3$ (opposite to p). Ratio 2 : 1. Falls as $1/r^3$.
- **Dipole in a uniform field:** net force zero, torque $\tau = pE \sin\theta$. Stable at $\theta = 0^\circ$, unstable at $\theta = 180^\circ$. In a non-uniform field it also feels a net force.
- **Electric flux** $\phi = E \cdot A = EA \cos\theta$ (unit N m²/C). Only enclosed charge matters in Gauss's law.
- **Gauss's law derivations:** Wire — cylinder: $E(2\pi rl) = \lambda l/\epsilon_0 \Rightarrow E = \lambda/2\pi\epsilon_0 r$. Sheet — pill box: $E(2A) = \sigma A/\epsilon_0 \Rightarrow E = \sigma/2\epsilon_0$. Shell — sphere: $E(4\pi r^2) = q/\epsilon_0$ outside; inside no charge $\Rightarrow E = 0$

(electrostatic shielding).

Key formulas

$$F = kq_1q_2/r^2, k = 9 \times 10^9 \text{ N m}^2/\text{C}^2$$

$$E = kq/r^2$$

$$\text{Line: } E = \lambda/2\pi\epsilon_0 r; \text{ Sheet: } E = \sigma/2\epsilon_0$$

$$\text{Shell (outside): } E = kq/r^2, \text{ inside: } 0$$

$$\varphi = q/\epsilon_0, \tau = pE \sin\theta$$

Quick 1-mark questions

Can two field lines cross?

No

Net force on a dipole in a uniform field?

Zero

SI unit of electric flux?

$\text{N m}^2/\text{C}$ (V m)

Solved problems (9)

Q1 Two charges of $1 \mu\text{C}$ each are 10 cm apart. Find the force between them.

$$1. F = kq_1q_2/r^2 = 9 \times 10^9 \times (10^{-6})^2 / (0.1)^2$$

$$2. = 9 \times 10^{-3} / 10^{-2}$$

✓ Answer: $F = 0.9 \text{ N}$ (repulsive)

Q2 Find the electric field 30 cm from a 2 nC charge.

$$1. E = kq/r^2 = 9 \times 10^9 \times 2 \times 10^{-9} / 0.09$$

$$2. = 18/0.09$$

✓ Answer: $E = 200 \text{ N/C}$

Q3 A closed surface encloses $8.85 \times 10^{-12} \text{ C}$. Find the electric flux through it.

$$1. \varphi = q/\epsilon_0 = 8.85 \times 10^{-12} / 8.85 \times 10^{-12}$$

✓ Answer: $\varphi = 1 \text{ N m}^2/\text{C}$

Q4 Charges $+3 \mu\text{C}$ and $-2 \mu\text{C}$ are 30 cm apart. Find the force.

$$1. F = 9 \times 10^9 \times 3 \times 10^{-6} \times 2 \times 10^{-6} / 0.09$$

✓ Answer: 0.6 N (attractive)

Q5 Charges $2 \mu\text{C}$ and $8 \mu\text{C}$ are 0.3 m apart. Where between them is E zero?

$$1. k(2)/x^2 = k(8)/(0.3 - x)^2 \Rightarrow (0.3 - x)/x = 2$$

$$2. 3x = 0.3$$

✓ Answer: 0.1 m from the $2 \mu\text{C}$ charge

Q6 A dipole has ± 2 nC charges 2 cm apart. Find p and the torque in a field of 10^5 N/C at 30° .

1. $p = q \times 2a = 2 \times 10^{-9} \times 0.02 = 4 \times 10^{-11}$ C m

2. $\tau = pE \sin\theta = 4 \times 10^{-11} \times 10^5 \times 0.5$

✓ Answer: $p = 4 \times 10^{-11}$ C m, $\tau = 2 \times 10^{-6}$ N m

Q7 How many electrons make a charge of -1 C?

1. $n = q/e = 1/1.6 \times 10^{-19}$

✓ Answer: 6.25×10^{18}

Q8 Find E at 10 cm from a long wire with $\lambda = 2$ μ C/m.

1. $E = \lambda/2\pi\epsilon_0 r = 2k\lambda/r = 2 \times 9 \times 10^9 \times 2 \times 10^{-6}/0.1$

✓ Answer: 3.6×10^5 N/C

Q9 A field of 200 N/C passes through an area of 0.1 m² making 60° with its normal. Find the flux.

1. $\phi = EA \cos\theta = 200 \times 0.1 \times 0.5$

✓ Answer: 10 N m²/C



Long answer questions (5 marks)

L1 Derive an expression for the electric field at a point on the axial line of an electric dipole.

Answer:

1. A dipole has charges $-q$ at A and $+q$ at B, separated by $2a$; dipole moment $p = q(2a)$, from $-q$ to $+q$.
2. Point P on the axis at distance r from the centre O (nearer $+q$).
3. Field due to $+q$: $E_+ = kq/(r - a)^2$ (along BP). Field due to $-q$: $E_- = kq/(r + a)^2$ (towards A).
4. Net $E = kq[1/(r - a)^2 - 1/(r + a)^2] = kq(4ar)/(r^2 - a^2)^2 = 2kp/(r^2 - a^2)^2$.
5. For a short dipole ($r \gg a$): $E_{\text{axial}} = 2kp/r^3$, in the direction of p .
6. (Similarly, on the equatorial line $E = kp/(r^2 + a^2)^{3/2} \approx kp/r^3$, opposite to p .)

★ Dipole field falls faster ($1/r^3$) than that of a single charge ($1/r^2$).

L2 State Gauss's theorem. Use it to find the electric field due to a uniformly charged thin spherical shell at points outside and inside.

Answer:

1. **Gauss's theorem:** total electric flux through any closed surface $= (1/\epsilon_0) \times$ total charge enclosed:
 $\oint E \cdot dA = q/\epsilon_0$.

2. Shell of radius R carries charge q . By symmetry, E is radial and has the same value at all points at distance r .
3. **Outside ($r > R$):** Gaussian sphere of radius r encloses q . $E(4\pi r^2) = q/\epsilon_0 \Rightarrow E = q/(4\pi\epsilon_0 r^2)$ — as if all charge is at the centre.
4. **On the surface ($r = R$):** $E = q/(4\pi\epsilon_0 R^2) = \sigma/\epsilon_0$.
5. **Inside ($r < R$):** Gaussian surface encloses no charge $\Rightarrow E(4\pi r^2) = 0 \Rightarrow E = 0$.

★ Zero field inside a shell is used for electrostatic shielding.

✓ Multiple choice questions (MCQs)

1. SI unit of charge is

- (a) ampere (b) coulomb
(c) volt (d) farad

2. If distance between two charges is halved, force becomes

- (a) half (b) double
(c) 4 times (d) $\frac{1}{4}$

3. Charge on an electron is

- (a) $1.6 \times 10^{-19} \text{ C}$ (b) $-1.6 \times 10^{-19} \text{ C}$
(c) $9.1 \times 10^{-31} \text{ C}$ (d) zero

4. Electric field inside a charged spherical shell is

- (a) maximum (b) zero
(c) kq/R^2 (d) infinite

5. Net force on a dipole in a uniform field is

- (a) pE (b) zero
(c) $2pE$ (d) $pE \sin\theta$

6. Unit of electric flux is

- (a) N/C (b) $\text{N m}^2/\text{C}$
(c) C/m^2 (d) V/m^2

7. Dipole field at large distance varies as

- (a) $1/r$ (b) $1/r^2$
(c) $1/r^3$ (d) r

8. Field due to an infinite plane sheet of charge is

- (a) σ/ϵ_0 (b) $\sigma/2\epsilon_0$
(c) $2\sigma/\epsilon_0$ (d) zero

Answer key: 1-(b) $1 \text{ C} = 1 \text{ A s}$. | 2-(c) $F \propto 1/r^2$. | 3-(b) Negative e. | 4-(b) No charge enclosed. | 5-(b) Forces cancel; only torque. | 6-(b) $\phi = EA$. | 7-(c) $E \propto p/r^3$. | 8-(b) Independent of distance.

02 Electrostatic Potential and Capacitance

Class XII · Unit I

In simple words

- **Potential V** = work done to bring unit positive charge from infinity to that point. Unit volt (V).
- **Equipotential surface**: all points have same V ; no work is done moving a charge on it. Field is perpendicular to it.
- Inside a **conductor**, $E = 0$ and all charge sits on the outer surface.
- A **dielectric** (insulator) gets polarised and reduces the field, so capacitance increases K times.
- **Capacitor** stores charge and energy. $C = Q/V$. Unit farad (F).

Remember in one line

- | | |
|--|--|
| 1 Potential = work per unit charge (volt). | 2 No work is done moving a charge on an equipotential surface. |
| 3 Inside a conductor, $E = 0$ and V is constant. | 4 Capacitor stores charge: $C = Q/V$. |
| 5 Dielectric increases capacitance K times. | 6 Energy in a capacitor = $\frac{1}{2}CV^2$. |

Theory in detail

Potential difference

The **potential difference** between two points is the work done to move a unit positive charge from one point to the other: $V_B - V_A = W_{AB}/q$. Unit: volt ($1 \text{ V} = 1 \text{ J/C}$). Because the electrostatic force is conservative, this work does not depend on the path taken. Positive charges naturally move from high to low potential; electrons move from low to high.

Free and bound charges

In a conductor, electrons are **free** to move through the whole material. In a dielectric, electrons are **bound** to their atoms — they can shift slightly but cannot leave. That slight shift (polarisation) produces surface charges that weaken the field inside. This is why putting a dielectric between capacitor plates allows more charge to be stored at the same voltage.

Uses of capacitors

Capacitors store energy and release it quickly (camera flash, defibrillator), smooth DC in power supplies (filter), block DC while passing AC (coupling), and with inductors form tuned circuits in radios. Capacitance is measured in farad; practical values are μF , nF and pF because 1 F is very large.

Potential due to a point charge

Moving a unit positive charge from infinity to a point at distance r from q requires work kq/r , so $V = kq/r$. V is positive for positive q and negative for negative q ; it decreases as $1/r$ (slower than E , which falls as $1/r^2$). At the same distance in all directions the potential is the same, so equipotential surfaces are spheres.

Electrostatic shielding

The field inside a hollow conductor is always zero, however strong the field outside. So sensitive instruments are kept in metal boxes, and a person inside a car is safe during lightning (the car body acts as a shield). This is also why electrical cables have a metal braid around them.

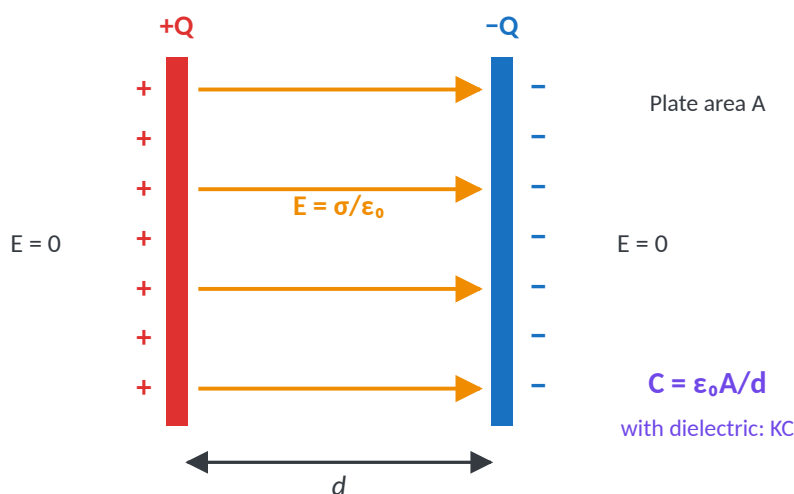


Fig. 2.1: Parallel plate capacitor: uniform field between the plates, zero outside

More theory - explained

- **E and V:** $E = -dV/dr$. The field points from high to low potential.
- **Dipole potential** $V = kp \cos\theta/r^2$: zero everywhere on the equatorial line.
- **System of charges:** $V = \sum kq_i/r_i$ — a simple (scalar) sum.
- **Equipotentials:** for a point charge — concentric spheres; for a uniform field — parallel planes perpendicular to E .
- **PE of charges:** add $kq_i q_j / r_{ij}$ for every pair. **Dipole in field:** $U = -pE \cos\theta$ (minimum when aligned).
- **Conductors in electrostatics:** $E = 0$ inside; whole conductor is equipotential; charge stays on the outer surface; E just outside $= \sigma/\epsilon_0$, perpendicular to surface; charge density is highest at sharp points (lightning conductor).
- **Dielectrics:** polar molecules (H_2O , HCl) have permanent dipoles; non-polar (O_2 , H_2) get induced dipoles. Polarisation creates an opposite field, so E inside $= E_0/K$.
- **Capacitance** depends on size, shape, gap and medium — not on Q or V . Series: same Q on each; parallel: same V across each.
- **Energy density** in an electric field: $u = \frac{1}{2}\epsilon_0 E^2$.
- **Inserting a dielectric:** battery connected $\Rightarrow V$ same, Q and U increase K times. Battery removed $\Rightarrow Q$ same, V and U decrease K times.

Key formulas

$$V = kq/r; \text{ Dipole axis: } V = kp/r^2$$

$$U \text{ (two charges)} = kq_1 q_2 / r$$

$$C = \epsilon_0 A / d; \text{ with dielectric } C = K\epsilon_0 A / d$$

Series: $1/C = 1/C_1 + 1/C_2$; Parallel: $C = C_1 + C_2$

Energy $U = \frac{1}{2}CV^2 = Q^2/2C$

⚡ Quick 1-mark questions

Potential inside a charged hollow conductor?

Constant, equal to surface value

Is potential a scalar or vector?

Scalar

Why is lightning conductor pointed?

High charge density at sharp points

✎ Solved problems (10)

Q1 Find the potential 20 cm from a $4 \mu\text{C}$ charge.

1. $V = kq/r = 9 \times 10^9 \times 4 \times 10^{-6} / 0.2$

✓ Answer: $V = 1.8 \times 10^5 \text{ V}$

Q2 Capacitors of $2 \mu\text{F}$ and $3 \mu\text{F}$ are joined (a) in series, (b) in parallel. Find net capacitance.

1. (a) $C = C_1C_2/(C_1+C_2) = 6/5$

2. (b) $C = 2 + 3$

✓ Answer: Series = $1.2 \mu\text{F}$, Parallel = $5 \mu\text{F}$

Q3 A parallel plate capacitor has $A = 0.01 \text{ m}^2$, $d = 1 \text{ mm}$. Find C ; then find C with a dielectric $K = 5$.

1. $C = \epsilon_0 A/d = 8.85 \times 10^{-12} \times 0.01 / 10^{-3} = 8.85 \times 10^{-11} \text{ F}$

2. With dielectric: $C' = KC = 5 \times 88.5 \text{ pF}$

✓ Answer: $C = 88.5 \text{ pF}$, $C' = 442.5 \text{ pF}$

Q4 A $10 \mu\text{F}$ capacitor is charged to 100 V. Find the energy stored.

1. $U = \frac{1}{2}CV^2 = \frac{1}{2} \times 10^{-5} \times 10^4$

✓ Answer: $U = 0.05 \text{ J}$

Q5 How much work is needed to move $2 \mu\text{C}$ from a point at 100 V to one at 300 V?

1. $W = q\Delta V = 2 \times 10^{-6} \times 200$

✓ Answer: $4 \times 10^{-4} \text{ J}$

Q6 Find the PE of charges $2 \mu\text{C}$ and $-3 \mu\text{C}$ kept 0.3 m apart.

1. $U = kq_1q_2/r = 9 \times 10^9 \times (-6 \times 10^{-12})/0.3$

✓ Answer: -0.18 J

Q7 Three $3\ \mu\text{F}$ capacitors: find C when (a) all in series (b) all parallel (c) two in series, that pair parallel with the third.

1. (a) $3/3 = 1\ \mu\text{F}$
2. (b) $3 + 3 + 3 = 9\ \mu\text{F}$
3. (c) $1.5 + 3 = 4.5\ \mu\text{F}$

✓ Answer: $1\ \mu\text{F}$, $9\ \mu\text{F}$, $4.5\ \mu\text{F}$

Q8 A $4\ \mu\text{F}$ capacitor at $100\ \text{V}$ is joined to an uncharged $4\ \mu\text{F}$ capacitor. Find common voltage and energy lost.

1. Charge $400\ \mu\text{C}$ is shared over $8\ \mu\text{F} \Rightarrow V = 50\ \text{V}$
2. $U_{\text{before}} = \frac{1}{2} \times 4 \times 10^{-6} \times 10^4 = 0.02\ \text{J}$
3. $U_{\text{after}} = \frac{1}{2} \times 8 \times 10^{-6} \times 2500 = 0.01\ \text{J}$

✓ Answer: $50\ \text{V}$; $0.01\ \text{J}$ lost (as heat)

Q9 $V = 5x^2$ volt. Find E at $x = 2\ \text{m}$.

1. $E = -dV/dx = -10x = -20$

✓ Answer: $20\ \text{V/m}$ in $-x$ direction

Q10 Charges totalling $4\ \mu\text{C}$ sit at the corners of a square, each $0.1\ \text{m}$ from its centre. Find V at the centre.

1. $V = k(\sum q)/r$ (scalar sum) $= 9 \times 10^9 \times 4 \times 10^{-6}/0.1$

✓ Answer: $3.6 \times 10^5\ \text{V}$

Long answer questions (5 marks)

L1 Derive the expression for the capacitance of a parallel plate capacitor (a) with air and (b) with a dielectric slab filling the gap.

Answer:

1. Two plates each of area A are separated by a small distance d ; charges $+Q$ and $-Q$; surface density $\sigma = Q/A$.
2. Field between the plates (from both sheets): $E = \sigma/2\epsilon_0 + \sigma/2\epsilon_0 = \sigma/\epsilon_0$; outside it is zero.
3. Potential difference $V = Ed = Qd/(\epsilon_0 A)$.
4. (a) $C_0 = Q/V = \epsilon_0 A/d$.
5. (b) A dielectric of constant K reduces the field to E/K , so V becomes V/K and $C = Q/V' = K\epsilon_0 A/d = KC_0$.
6. Capacitance increases with larger area, smaller gap and higher dielectric constant.

★ Dielectric increases capacitance K times.

L2 Derive expressions for equivalent capacitance of capacitors in series and in parallel. Write the energy stored in a capacitor.

Answer:

1. **Series:** the same charge Q sits on each capacitor; voltages add: $V = V_1 + V_2 + V_3 = Q/C_1 + Q/C_2 + Q/C_3$.
2. $V/Q = 1/C \Rightarrow 1/C = 1/C_1 + 1/C_2 + 1/C_3$. Net C is less than the smallest.
3. **Parallel:** the same V across each; charges add: $Q = C_1V + C_2V + C_3V$.
4. $Q/V = C \Rightarrow C = C_1 + C_2 + C_3$. Net C is more than the largest.
5. **Energy stored** (work done in charging): $U = \frac{1}{2}CV^2 = \frac{1}{2}QV = Q^2/2C$. It is stored in the electric field between the plates.

★ Series combination reduces C ; parallel increases it.

✓ Multiple choice questions (MCQs)

- | | |
|---|---|
| 1. SI unit of capacitance is
(a) volt (b) farad
(c) coulomb (d) ohm | 2. Potential due to a point charge varies as
(a) $1/r$ (b) $1/r^2$
(c) r (d) $1/r^3$ |
| 3. Two $4\ \mu\text{F}$ capacitors in series give
(a) $8\ \mu\text{F}$ (b) $2\ \mu\text{F}$
(c) $4\ \mu\text{F}$ (d) $16\ \mu\text{F}$ | 4. Energy stored in a capacitor is
(a) CV (b) $\frac{1}{2}CV^2$
(c) C^2V (d) $\frac{1}{2}QV^2$ |
| 5. Electric field and equipotential surface are
(a) parallel (b) perpendicular
(c) at 45° (d) any angle | 6. Placing a dielectric (K) between plates makes C
(a) C/K (b) KC
(c) C (d) K^2C |
| 7. Potential on the equatorial line of a dipole is
(a) maximum (b) zero
(c) kp/r^2 (d) negative | 8. Capacitance of a parallel plate capacitor is
(a) $\epsilon_0 A/d$ (b) $\epsilon_0 d/A$
(c) $A/\epsilon_0 d$ (d) $\epsilon_0 Ad$ |

Answer key: 1-(b) $C = Q/V$. | 2-(a) $V = kq/r$. | 3-(b) $C/2$. | 4-(b) Standard result. | 5-(b) No work along surface. | 6-(b) Field reduced K times. | 7-(b) $\cos 90^\circ = 0$. | 8-(a) Standard result.

In simple words

- **Current** I = rate of flow of charge ($I = q/t$). In metals, free electrons drift slowly opposite to the field (**drift velocity**).
- **Ohm's law**: $V = IR$ (at constant temperature). Materials following it give a straight V - I graph (linear); diodes do not (non-linear).
- **Resistivity** ρ depends on material and temperature. For metals, resistance increases with temperature.
- A cell has **emf** E and **internal resistance** r . Terminal voltage $V = E - Ir$.
- **Kirchhoff's rules**: (1) Junction: current in = current out. (2) Loop: sum of potential changes = 0.
- **Wheatstone bridge** is balanced when $P/Q = R/S$ (no current in galvanometer).

Remember in one line

- | | |
|---|---|
| ① Current = rate of flow of charge (ampere). | ② Electrons drift slowly opposite to the field. |
| ③ Ohm's law: $V = IR$ at constant temperature. | ④ Resistance of metals rises with temperature. |
| ⑤ Kirchhoff: junction rule (charge) + loop rule (energy). | ⑥ Bridge balance: $P/Q = R/S$. |

Theory in detail

Flow of charge in a metal

A metal has a huge number of free electrons moving randomly at high speeds ($\sim 10^5$ m/s), but their average velocity is zero, so no current flows. When a battery is connected, an electric field acts and electrons slowly drift towards the positive end with a tiny **drift velocity** ($\sim 10^{-4}$ m/s). The bulb still glows instantly because the field is set up throughout the wire almost at the speed of light.

Resistance and resistivity

Resistance is the opposition offered by a conductor to current; it depends on length, area, material and temperature ($R = \rho L/A$). **Resistivity** ρ depends only on the material and temperature. Conductivity $\sigma = 1/\rho$. Silver and copper have very low ρ ; nichrome has high ρ and is used in heaters.

EMF vs terminal voltage

EMF (E) is the work done by a cell in moving unit charge round the complete circuit; it is the p.d. across the cell when no current is drawn. **Terminal voltage V** is the p.d. across the cell when current flows: $V = E - Ir$. While charging a cell, $V = E + Ir$. Internal resistance increases as a cell gets old.

V-I characteristics

For an ohmic conductor, the V-I graph is a straight line through the origin (constant resistance). Non-ohmic devices give curves: a filament bulb's resistance rises as it heats up; a diode conducts only one way; in some materials (like GaAs) current can even decrease as voltage increases in some region. Ohm's law is therefore not a universal law.

Electrical energy and power

When current I flows through a potential difference V for time t , energy used = VIt and power $P = VI = I^2R = V^2/R$. This energy appears as heat (Joule heating), used in heaters, irons and fuses. Household devices are connected in parallel so that each gets full voltage and can be switched independently.

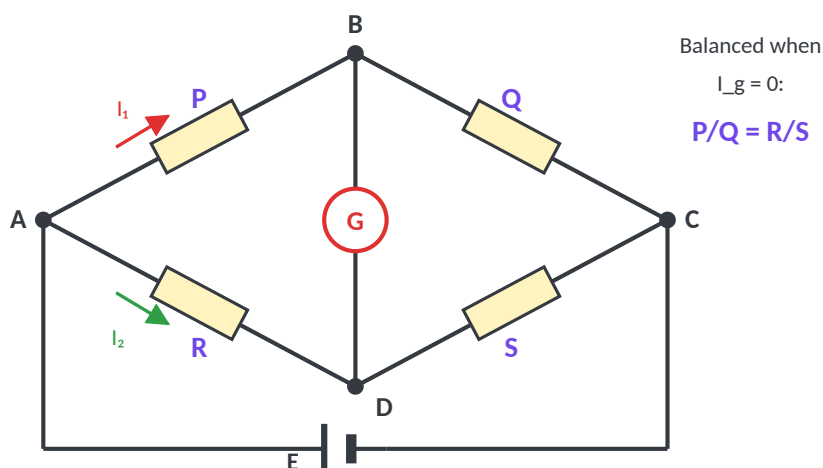


Fig. 3.1: Wheatstone bridge

More theory - explained

- **Current:** conventional current flows + to -, opposite to electrons. It has direction but is a **scalar** (does not obey vector addition).
- **Drift velocity** $v_d = eE\tau/m$ (τ = relaxation time). From it: $I = neAv_d$, $J = \sigma E$ (microscopic Ohm's law), $\rho = m/(ne^2\tau)$.
- **Mobility** $\mu = v_d/E = e\tau/m$ (unit $m^2/V\ s$).
- **Temperature effects:** metals — ρ rises (τ falls). Semiconductors — ρ falls (more carriers). Alloys (manganin, constantan, nichrome) — very small α , so used for standard resistors and heaters.
- **Colour code:** Black 0, Brown 1, Red 2, Orange 3, Yellow 4, Green 5, Blue 6, Violet 7, Grey 8, White 9 (*BB ROY of Great Britain has a Very Good Wife*). Gold $\pm 5\%$, Silver $\pm 10\%$.
- **Cells in series:** $E = E_1 + E_2$, $r = r_1 + r_2$. **In parallel:** $E_{eq} = (E_1r_2 + E_2r_1)/(r_1 + r_2)$, $1/r_{eq} = 1/r_1 + 1/r_2$.
- **Kirchhoff's rules:** junction rule comes from conservation of charge; loop rule from conservation of energy.
- **Metre bridge** (Wheatstone bridge in practice): $R/S = l/(100 - l)$.
- **Non-ohmic devices:** diode, thermistor, GaAs — V-I graph not a straight line, or different for reverse V.

- **Energy:** 1 kWh (1 unit) = 3.6×10^6 J. In series the bulb of higher R glows brighter; in parallel the lower R glows brighter.

🔑 Key formulas

$$I = neAv_d; \text{ mobility } \mu = v_d/E$$

$$R = \rho L/A; R_T = R_0(1 + \alpha \Delta T)$$

$$\text{Series } R = R_1 + R_2; \text{ Parallel } 1/R = 1/R_1 + 1/R_2$$

$$I = E/(R + r)$$

$$P = VI = I^2R = V^2/R$$

🔍 Quick 1-mark questions

Effect of heating on R of a semiconductor?

Decreases

SI unit of resistivity?

$\Omega \text{ m}$

Why is manganin used in standard resistors?

Very low temperature coefficient

📝 Solved problems (10)

Q1 A cell of emf 12 V and internal resistance 1 Ω is connected to a 5 Ω resistor. Find the current and terminal voltage.

$$1. I = E/(R + r) = 12/(5 + 1) = 2 \text{ A}$$

$$2. V = E - Ir = 12 - 2 \times 1$$

✓ **Answer: $I = 2 \text{ A}$, $V = 10 \text{ V}$**

Q2 A Wheatstone bridge has $P = 10 \Omega$, $Q = 20 \Omega$, $R = 15 \Omega$. Find S for balance.

$$1. P/Q = R/S \Rightarrow S = RQ/P = 15 \times 20/10$$

✓ **Answer: $S = 30 \Omega$**

Q3 A copper wire ($A = 1 \text{ mm}^2$, $n = 8.5 \times 10^{28} \text{ m}^{-3}$) carries 1.5 A. Find the drift velocity.

$$1. v_d = I/(neA) = 1.5 / (8.5 \times 10^{28} \times 1.6 \times 10^{-19} \times 10^{-6})$$

$$2. = 1.5 / 1.36 \times 10^4$$

✓ **Answer: $v_d \approx 1.1 \times 10^{-4} \text{ m/s}$ (very slow!)**

Q4 Find R of a 10 m copper wire of area 1 mm^2 . ($\rho = 1.7 \times 10^{-8} \Omega \text{ m}$)

$$1. R = \rho L/A = 1.7 \times 10^{-8} \times 10/10^{-6}$$

✓ **Answer: 0.17Ω**

Q5 A wire is stretched to double its length. What happens to R?

1. Volume same $\Rightarrow A$ becomes half

$$2. R = \rho L/A \Rightarrow R' = \rho(2L)/(A/2) = 4R$$

✓ **Answer: R becomes 4 times**

Q6 $R = 10\ \Omega$ at $20\ ^\circ\text{C}$, $\alpha = 0.004\ ^\circ\text{C}^{-1}$. Find R at $120\ ^\circ\text{C}$.

1. $R = R_0(1 + \alpha\Delta T) = 10(1 + 0.004 \times 100)$

✓ Answer: $14\ \Omega$

Q7 In a metre bridge, balance is at 40 cm with $R = 2\ \Omega$ in the left gap. Find S .

1. $S = R(100 - l)/l = 2 \times 60/40$

✓ Answer: $3\ \Omega$

Q8 Four cells (1.5 V, $0.5\ \Omega$ each) in series feed a $4\ \Omega$ resistor. Find current.

1. $E = 6\ \text{V}$, $r = 2\ \Omega$

2. $I = 6/(4 + 2)$

✓ Answer: $1\ \text{A}$

Q9 A bulb is rated 100 W, 220 V. Find R , current, and energy used in 10 h.

1. $R = V^2/P = 48400/100 = 484\ \Omega$

2. $I = P/V \approx 0.45\ \text{A}$

3. $E = 0.1\ \text{kW} \times 10\ \text{h}$

✓ Answer: $484\ \Omega$, $0.45\ \text{A}$, $1\ \text{kWh}$

Q10 Find the resistance with bands Brown, Black, Red, Gold.

1. $1, 0, \times 10^2, \pm 5\%$

✓ Answer: $1000\ \Omega \pm 5\%$



Long answer questions (5 marks)

L1 Define drift velocity. Derive the relation between current and drift velocity. Hence deduce Ohm's law.

Answer:

- Drift velocity:** the average velocity with which free electrons move opposite to the applied field.
- In field E , each electron has acceleration $a = -eE/m$. Average time between collisions = relaxation time $\tau \Rightarrow v_d = eE\tau/m$ (magnitude).
- In a wire of area A with n electrons per unit volume, in time Δt , electrons in volume $Av_d\Delta t$ cross a section: charge = $neAv_d\Delta t \Rightarrow I = neAv_d$.
- Substitute v_d : $I = neA(eE\tau/m) = (ne^2\tau/m)A(V/l)$.
- $V/l = (m/ne^2\tau)(I/A) = R$, a constant at fixed temperature $\Rightarrow V = IR$ (Ohm's law), with $\rho = m/(ne^2\tau)$.

★ Ohm's law follows from the drift of electrons.

L2 State Kirchhoff's rules and derive the balancing condition of a Wheatstone bridge.

Answer:

1. **Junction rule:** sum of currents entering a junction = sum leaving (charge conservation).
2. **Loop rule:** in any closed loop, algebraic sum of potential changes = 0 (energy conservation).
3. Bridge: P (AB), Q (BC), R (AD), S (DC); battery across A and C; galvanometer G between B and D.
4. At balance, $I_g = 0$, so the current I_1 flows through P and Q, and I_2 through R and S.
5. Loop ABDA: $-I_1P + I_2R = 0$. Loop BCDB: $-I_1Q + I_2S = 0$.
6. Dividing: $P/Q = R/S \Rightarrow \mathbf{P/Q = R/S}$ (balance condition). An unknown S can be found from known P, Q, R.

★ The metre bridge works on this principle.

✓ Multiple choice questions (MCQs)

1. SI unit of resistivity is

- (a) Ω (b) $\Omega \text{ m}$
(c) Ω/m (d) S

2. Drift velocity of electrons is of the order of

- (a) 10^8 m/s (b) 10^5 m/s
(c) 10^{-4} m/s (d) 1 m/s

3. Resistance of a metal wire on heating

- (a) decreases (b) increases
(c) stays same (d) becomes zero

4. Kirchhoff's junction rule is based on conservation of

- (a) energy (b) charge
(c) momentum (d) mass

5. A wire is stretched to double length. Its resistance becomes

- (a) $2R$ (b) $4R$
(c) $R/2$ (d) R

6. Terminal voltage of a cell delivering current is

- (a) $E + Ir$ (b) $E - Ir$
(c) E (d) Ir

7. Resistors 2Ω and 3Ω in parallel give

- (a) 5Ω (b) 1.2Ω
(c) 6Ω (d) 0.83Ω

8. Metre bridge works on the principle of

- (a) potentiometer (b) Wheatstone bridge
(c) Ohm's law only (d) Joule heating

Answer key: 1-(b) $\rho = RA/L$. | 2-(c) Very slow. | 3-(b) More collisions. | 4-(b) Charge can't pile up. | 5-(b) L doubles, A halves. | 6-(b) Drop in internal resistance. | 7-(b) $6/5$. | 8-(b) Balanced bridge.

04 Moving Charges and Magnetism

Class XII · Unit III

In simple words

- **Oersted** showed that a current produces a magnetic field around it.
- **Biot-Savart law** gives the field due to a small current element. **Ampere's law:** $\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I$.
- A charge moving in a magnetic field feels **Lorentz force** $\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$. If $\mathbf{v} \perp \mathbf{B}$, it moves in a circle.
- Two parallel wires with current in the **same direction attract**, opposite directions repel. This defines the ampere.
- A current loop acts like a **magnetic dipole**, $m = NIA$, and feels torque $\tau = mB \sin\theta$.
- **Galvanometer** → **ammeter**: small shunt in parallel. → **voltmeter**: large resistance in series.

Remember in one line

- | | |
|---|--|
| 1 A current produces a magnetic field around it. | 2 Field at centre of loop = $\mu_0 I / 2R$; near long wire = $\mu_0 I / 2\pi r$. |
| 3 Magnetic force on a charge is $\perp$ to its velocity — no work done. | 4 Parallel currents in the same direction attract. |
| 5 A current loop behaves like a tiny magnet. | 6 Ammeter = galvanometer + small shunt; voltmeter = galvanometer + big series R. |

Theory in detail

Oersted's discovery

In 1820 Oersted noticed that a compass needle placed near a wire deflected when current flowed and reversed when the current reversed. This showed for the first time that **electricity and magnetism are linked**: moving charges (currents) produce magnetic fields. Magnetic field B is measured in tesla (T); 1 gauss = 10^{-4} T.

Right-hand rules

Right-hand thumb rule: hold a straight wire with the thumb along current; curled fingers show the field direction. For a loop/solenoid, curl fingers along current; thumb gives the N pole direction. **Fleming's left-hand rule** for force on a current: forefinger – field, middle finger – current, thumb – force (motion).

Galvanometer, ammeter and voltmeter

A galvanometer detects small currents. To measure large currents (**ammeter**), connect a low resistance **shunt** in parallel so most current bypasses the coil; an ammeter is put in series and must have very low resistance. To measure voltage (**voltmeter**), add a high resistance in series; it is connected in parallel and must have very high resistance so it draws little current.

Ampere's circuital law

The line integral of magnetic field around any closed loop equals μ_0 times the total current passing through the loop: $\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I$. It plays the same role for magnetism as Gauss's law plays for electricity. It is easy to use when the field has symmetry, such as around a long straight wire or inside a solenoid.

Current loop as a magnetic dipole

A small loop carrying current behaves just like a tiny bar magnet: one face acts as a N pole and the other as a S pole. Its magnetic moment $\mathbf{m} = I\mathbf{A}$ points perpendicular to the loop (right-hand rule). In a uniform field it feels a torque that turns it to align $\mathbf{m}$ with $\mathbf{B}$ — this is the working principle of electric motors and galvanometers.

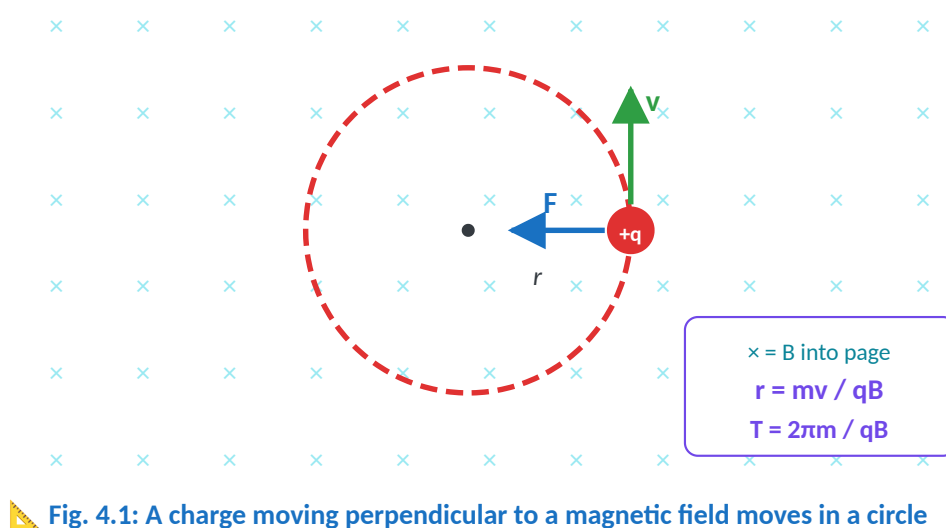


Fig. 4.1: A charge moving perpendicular to a magnetic field moves in a circle

More theory - explained

- **Biot-Savart law:** $dB = (\mu_0/4\pi) I dl \sin\theta/r^2$, $\mu_0 = 4\pi \times 10^{-7} \text{ T m/A}$.
- **Field on the axis of a loop:** $B = \mu_0 I R^2 / 2(R^2 + x^2)^{3/2}$; at centre ($x = 0$) $B = \mu_0 I / 2R$. Direction by right-hand thumb rule; a clockwise current face acts as S pole.
- **Ampere's law** for a long wire: $B(2\pi r) = \mu_0 I \Rightarrow B = \mu_0 I / 2\pi r$. Field lines are circles round the wire.
- **Solenoid:** inside $B = \mu_0 nI$ (uniform), outside ≈ 0 . **Toroid:** $B = \mu_0 NI / 2\pi r$ inside, zero outside.
- **Lorentz force** $\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$. Magnetic force is $\perp \mathbf{v}$, so it does **no work** and speed stays constant.
- **Circular motion** in $\mathbf{B}$: $r = mv/qB$, $T = 2\pi m/qB$ (does not depend on speed — basis of cyclotron). At an angle, path is a helix. **Velocity selector:** crossed $\mathbf{E}$ and $\mathbf{B}$ pass only $\mathbf{v} = \mathbf{E}/\mathbf{B}$.
- **Force on conductor** $\mathbf{F} = I \mathbf{L} \times \mathbf{B}$; direction by Fleming's left-hand rule.
- **Definition of ampere:** the current which, in two long parallel wires 1 m apart in vacuum, produces a force of $2 \times 10^{-7} \text{ N per metre}$.
- **Current loop as dipole:** $\mathbf{m} = NIA$, $\boldsymbol{\tau} = \mathbf{m} \times \mathbf{B} = NIAB \sin\theta$.

- **Moving coil galvanometer:** radial field makes $\tau = NIAB$; spring gives $k\phi \Rightarrow \phi = (NAB/k)I$. Current sensitivity = NAB/k ; voltage sensitivity = NAB/kR . Increase N , A , B or use weak spring to make it more sensitive.

Key formulas

Centre of loop: $B = \mu_0 NI/2R$

Long wire: $B = \mu_0 I/2\pi r$; Solenoid: $B = \mu_0 nI$

$F = qvB \sin\theta$; $r = mv/qB$

F on wire = $BIL \sin\theta$; $F/L = \mu_0 I_1 I_2 / 2\pi d$

Shunt $S = I_g G / (I - I_g)$; Series $R = V/I_g - G$

Quick 1-mark questions

Does a magnetic force change the KE of a charge?

No, it does no work

Resistance of an ideal ammeter / voltmeter?

Zero / infinite

Why is the field made radial in an MCG?

Torque stays maximum, scale becomes linear

Solved problems (9)

Q1 Find B at the centre of a circular loop of radius 10 cm carrying 5 A.

1. $B = \mu_0 I / 2R = 4\pi \times 10^{-7} \times 5 / (2 \times 0.1)$

✓ Answer: $B \approx 3.14 \times 10^{-5} \text{ T}$

Q2 Find B at 5 cm from a long straight wire carrying 10 A.

1. $B = \mu_0 I / 2\pi r = 2 \times 10^{-7} \times 10 / 0.05$

✓ Answer: $B = 4 \times 10^{-5} \text{ T}$

Q3 A galvanometer ($G = 50 \Omega$) gives full deflection at 5 mA. Convert it into (a) a 5 A ammeter, (b) a 10 V voltmeter.

1. (a) $S = I_g G / (I - I_g) = 0.005 \times 50 / 4.995 \approx 0.05 \Omega$ in parallel

2. (b) $R = V/I_g - G = 10/0.005 - 50 = 1950 \Omega$ in series

✓ Answer: Shunt $\approx 0.05 \Omega$; Series resistance = 1950Ω

Q4 A solenoid has 1000 turns per metre and carries 2 A. Find B inside.

1. $B = \mu_0 nI = 4\pi \times 10^{-7} \times 1000 \times 2$

✓ Answer: $\approx 2.5 \times 10^{-3} \text{ T}$

Q5 Two parallel wires 10 cm apart carry 5 A and 10 A in the same direction. Find force per metre.

1. $F/L = \mu_0 I_1 I_2 / 2\pi d = 2 \times 10^{-7} \times 50 / 0.1$

✓ Answer: 10^{-4} N/m, attractive

Q6 A proton moves at 10^6 m/s perpendicular to $B = 0.5$ T. Find the radius of its path.

1. $r = mv/qB = 1.67 \times 10^{-27} \times 10^6 / (1.6 \times 10^{-19} \times 0.5)$

✓ Answer: ≈ 2.1 cm

Q7 A 0.5 m wire with 4 A lies perpendicular to $B = 0.2$ T. Find the force on it.

1. $F = BIL = 0.2 \times 4 \times 0.5$

✓ Answer: 0.4 N

Q8 A 100-turn coil of area $2 \times 10^{-3} \text{ m}^2$ with 2 A is in $B = 0.5$ T with its plane parallel to B. Find m and torque.

1. $m = NIA = 100 \times 2 \times 2 \times 10^{-3} = 0.4 \text{ A m}^2$

2. θ (between m and B) = $90^\circ \Rightarrow \tau = mB = 0.4 \times 0.5$

✓ Answer: $m = 0.4 \text{ A m}^2$, $\tau = 0.2 \text{ N m}$

Q9 In a velocity selector $E = 10^4$ V/m and $B = 0.02$ T. Which speed passes undeflected?

1. $v = E/B = 10^4 / 0.02$

✓ Answer: 5×10^5 m/s



Long answer questions (5 marks)

L1 Using Biot-Savart law, derive the magnetic field on the axis of a circular current loop. Find the field at its centre.

Answer:

1. A loop of radius R carries current I . Point P is on the axis at distance x from the centre.
2. An element dl at the top is perpendicular to the line joining it to P (distance $r = \sqrt{R^2 + x^2}$). $dB = (\mu_0/4\pi) I dl/r^2$.
3. dB has components along the axis ($dB \cos\alpha$) and perpendicular ($dB \sin\alpha$). Perpendicular parts cancel for opposite elements.
4. $\cos\alpha = R/r \Rightarrow B = \int dB \cos\alpha = (\mu_0 I/4\pi)(R/r^3) \int dl = (\mu_0 I/4\pi)(R/r^3)(2\pi R)$.
5. $B = \mu_0 I R^2 / [2(R^2 + x^2)^{3/2}]$ along the axis.
6. At the centre ($x = 0$): $B = \mu_0 I / 2R$; for N turns, $B = \mu_0 NI / 2R$.

★ The field is strongest at the centre and falls off along the axis.

L2 Derive the force between two long parallel current-carrying wires. Define one ampere.

Answer:

1. Wires a and b are separated by d and carry currents I_a and I_b .
2. Field of wire a at b (Ampere's law): $B_a = \mu_0 I_a / 2\pi d$, perpendicular to wire b.
3. Force on length L of b: $F_{ba} = I_b L B_a = \mu_0 I_a I_b L / 2\pi d$.
4. Force per unit length $f = \mu_0 I_a I_b / 2\pi d$. By Fleming's rule: same direction currents **attract**, opposite currents repel.
5. **One ampere**: the current which, flowing in two infinitely long parallel wires 1 m apart in vacuum, produces a force of 2×10^{-7} N per metre of length.

★ This force is used to define the SI unit of current.

✓ Multiple choice questions (MCQs)

1. SI unit of magnetic field is

- (a) weber (b) tesla
(c) henry (d) gauss

2. Force on a charge moving parallel to B is

- (a) qvB (b) zero
(c) maximum (d) qB/v

3. Two parallel wires with currents in the same direction

- (a) attract (b) repel
(c) no force (d) rotate

4. Field inside a long solenoid is

- (a) zero (b) $\mu_0 nI$
(c) $\mu_0 I / 2R$ (d) $\mu_0 I / 2\pi r$

5. A galvanometer is converted into an ammeter by connecting

- (a) high R in series (b) low R in parallel
(c) high R in parallel (d) low R in series

6. Magnetic force on a moving charge does work equal to

- (a) qvB (b) zero
(c) $\frac{1}{2}mv^2$ (d) qE

7. Radius of path of a charge in B is

- (a) mv/qB (b) qB/mv
(c) $mvqB$ (d) m/qvB

8. Magnetic moment of a current loop is

- (a) IA (b) I/A
(c) IA^2 (d) A/I

Answer key: 1-(b) $1 \text{ T} = 1 \text{ N}/(\text{A m})$. | 2-(b) $\sin 0^\circ = 0$. | 3-(a) Standard result. | 4-(b) Uniform inside. | 5-(b) Shunt. | 6-(b) $F \perp v$. | 7-(a) $qvB = mv^2/r$. | 8-(a) $m = NIA$.

05 Magnetism and Matter

Class XII · Unit III

In simple words

- A **bar magnet** behaves like a current-carrying solenoid. Its field lines go $N \rightarrow S$ outside and $S \rightarrow N$ inside (closed loops).
- In a uniform field a bar magnet feels a **torque** that tries to align it with the field (like a compass).
- **Diamagnetic** (Cu, Bi, water): weakly repelled, χ small negative.
- **Paramagnetic** (Al, Na, O_2): weakly attracted, χ small positive.
- **Ferromagnetic** (Fe, Co, Ni): strongly attracted, χ very large. Above the **Curie temperature** they become paramagnetic.
- Heating reduces magnetism of para- and ferromagnets (**Curie law**: $\chi \propto 1/T$).

Remember in one line

- | | |
|--|---|
| 1 A bar magnet behaves like a current-carrying solenoid. | 2 Magnetic poles always come in pairs. |
| 3 Field lines are closed loops. | 4 Diamagnets are weakly repelled; paramagnets weakly attracted. |
| 5 Ferromagnets are strongly attracted (Fe, Co, Ni). | 6 Heating reduces magnetism (Curie law, Curie temperature). |

Theory in detail

Bar magnet and solenoid

Iron filings around a bar magnet and around a current-carrying solenoid make exactly the same pattern. Cutting a solenoid in half gives two smaller solenoids, just as cutting a magnet gives two magnets. So a bar magnet behaves like a solenoid; its magnetism comes from tiny circulating currents (electron motion) inside atoms.

Magnetic field lines

Magnetic field lines are imaginary lines whose tangent gives the direction of B . They form **closed loops** (outside from N to S, inside from S to N), never intersect, and are crowded where the field is strong. Unlike electric lines they do not start or end on any 'charge', because magnetic monopoles do not exist.

Magnetisation and temperature

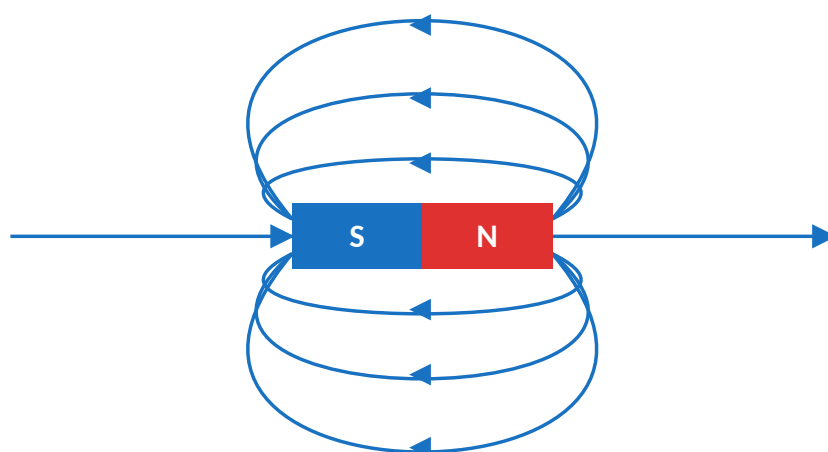
When a material is placed in a field, its atomic magnetic moments may line up — this is **magnetisation**. Heat makes atoms vibrate and disturbs this alignment. So paramagnetic susceptibility falls with temperature (Curie law), and ferromagnets lose their strong magnetism above the **Curie temperature**. Diamagnetism is almost unaffected by temperature.

Bar magnet in a uniform field

A freely suspended magnet in a uniform field (like Earth's) feels equal and opposite forces on its poles, so it does not move as a whole but rotates until it lines up with the field. That is how a compass works. If disturbed slightly it oscillates about the field direction, with a period that depends on its moment of inertia, magnetic moment and field.

Earth's magnetism

Earth behaves like a huge bar magnet whose south pole is near the geographic north. Its field is described by declination (angle between geographic and magnetic meridian), dip or inclination (angle of the field with the horizontal) and horizontal component. The field comes from electric currents in the molten iron core.



Field lines are closed loops: $N \rightarrow S$ outside, $S \rightarrow N$ inside

 Fig. 5.1: Magnetic field lines of a bar magnet

More theory - explained

- **No monopoles:** cutting a magnet always gives two smaller magnets. Gauss's law for magnetism: net flux through any closed surface = 0.
- **Magnetic moment** of a bar magnet $m = q_m \times 2l$, directed $S \rightarrow N$ (inside the magnet).
- **Fields of a short magnet:** axial $B = (\mu_0/4\pi)(2m/r^3)$; equatorial $B = (\mu_0/4\pi)(m/r^3)$, opposite to m .
- **Energy of a magnet** in B : $U = -mB \cos\theta$; work to turn from θ_1 to $\theta_2 = mB(\cos\theta_1 - \cos\theta_2)$.
- **Magnetic quantities:** magnetisation $M = m/V$; intensity H ; $B = \mu_0(H + M)$; $\chi = M/H$; $\mu_r = 1 + \chi$; $\mu = \mu_0\mu_r$.
- **Diamagnetism:** no permanent atomic moments; applied field induces opposing moments $\Rightarrow$ moves to weaker field. Superconductors are perfect diamagnets (Meissner effect).
- **Paramagnetism:** atoms have permanent moments that are randomly arranged; field partly lines them up. Heat disturbs this $\Rightarrow$ Curie law $\chi = C/T$.
- **Ferromagnetism:** tiny regions called **domains** are already aligned; a field grows and turns them. Above Curie temperature (Fe: 1043 K) it becomes paramagnetic.
- **Soft iron vs steel:** soft iron (high μ , low retentivity & coercivity) — electromagnets, transformer cores. Steel (high retentivity & coercivity) — permanent magnets.

Key formulas

$$\tau = mB \sin\theta$$

$$\text{Axial field} \propto 2m/r^3; \text{Equatorial} \propto m/r^3$$

$$M = m/V \text{ (magnetisation)}$$

$$\chi = M/H; \mu_r = 1 + \chi$$

$$\text{Curie law: } \chi = C/T$$

Quick 1-mark questions

Can an isolated magnetic pole exist?

No

Why is soft iron used in electromagnets?

High permeability, low retentivity

Susceptibility sign for diamagnets?

Negative

Solved problems (7)

Q1 A bar magnet of moment 2 A m^2 is at 30° to a field of 0.5 T . Find the torque.

$$1. \tau = mB \sin\theta = 2 \times 0.5 \times \sin 30^\circ = 1 \times 0.5$$

✓ Answer: $\tau = 0.5 \text{ N m}$

Q2 The susceptibility of a paramagnetic salt is 2×10^{-4} at 300 K . Find it at 150 K .

$$1. \chi \propto 1/T \Rightarrow \chi_2 = \chi_1(T_1/T_2) = 2 \times 10^{-4} \times 2$$

✓ Answer: $\chi = 4 \times 10^{-4}$

Q3 A short magnet ($m = 0.5 \text{ A m}^2$): find B at 10 cm on its axis and on its equatorial line.

$$1. \text{Axial: } B = 10^{-7} \times 2 \times 0.5 / (0.1)^3 = 10^{-4} \text{ T}$$

2. Equatorial: half of axial

✓ Answer: $10^{-4} \text{ T}; 5 \times 10^{-5} \text{ T}$

Q4 Find work to turn a magnet ($m = 2 \text{ A m}^2$) in $B = 0.1 \text{ T}$ from 0° to (a) 90° (b) 180° .

$$1. W = mB(\cos 0^\circ - \cos\theta)$$

$$2. (a) 0.2 \times (1 - 0)$$

$$3. (b) 0.2 \times (1 - (-1))$$

✓ Answer: $0.2 \text{ J}; 0.4 \text{ J}$

Q5 A 500-turn solenoid of area 10^{-4} m^2 carries 2 A . Find its magnetic moment.

$$1. m = NIA = 500 \times 2 \times 10^{-4}$$

✓ Answer: 0.1 A m^2

Q6 A material has $\chi = 599$. Find μ_r and μ .

1. $\mu_r = 1 + \chi = 600$
2. $\mu = 600 \times 4\pi \times 10^{-7}$

✓ Answer: $\mu_r = 600$, $\mu \approx 7.5 \times 10^{-4} \text{ T m/A}$

Q7 $H = 1000 \text{ A/m}$ acts on a material with $\chi = 2 \times 10^{-4}$. Find M .

1. $M = \chi H = 2 \times 10^{-4} \times 1000$

✓ Answer: 0.2 A/m

Long answer questions (5 marks)

L1 Explain the torque acting on a bar magnet in a uniform magnetic field and derive the expression for its potential energy.

Answer:

1. A magnet of moment m is placed at angle θ with a uniform field B . Its N pole feels force along B and S pole opposite to B ; net force = 0.
2. These equal and opposite forces form a couple; torque $\tau = mB \sin\theta$ (vector form $\tau = m \times B$). It tries to align m with B .
3. Work done to turn the magnet by $d\theta$ against the torque: $dW = mB \sin\theta d\theta$.
4. Taking $U = 0$ at $\theta = 90^\circ$: $U = \int_{90^\circ}^{\theta} mB \sin\theta d\theta = -mB \cos\theta = -m \cdot B$.
5. $\theta = 0^\circ$: $U = -mB$ (minimum, stable). $\theta = 180^\circ$: $U = +mB$ (maximum, unstable).

★ A compass needle settles along the field because that is the lowest-energy position.

L2 Compare dia-, para- and ferromagnetic substances.

Answer:

1. **Behaviour in a field:** dia – weakly repelled, moves to weaker field; para – weakly attracted to stronger field; ferro – strongly attracted.
2. **Susceptibility χ :** dia – small negative (-10^{-5}); para – small positive (10^{-5} to 10^{-3}); ferro – very large positive (10^3 or more).
3. **Relative permeability:** dia $\mu_r < 1$; para slightly > 1 ; ferro $\gg 1$.
4. **Cause:** dia – no permanent atomic moment, induced moments oppose field; para – permanent moments randomly oriented; ferro – aligned domains.
5. **Temperature:** dia – independent; para – $\chi \propto 1/T$; ferro – becomes para above Curie point.
6. **Examples:** dia – Bi, Cu, Pb, water, N_2 ; para – Al, Na, Ca, O_2 ; ferro – Fe, Co, Ni, Gd.

★ The difference comes from how atomic magnetic moments behave.

✓ Multiple choice questions (MCQs)

1. Which is diamagnetic?

- (a) Iron
- (b) Aluminium
- (c) Copper
- (d) Nickel

2. Susceptibility of a diamagnetic substance is

- (a) large positive
- (b) small positive
- (c) small negative
- (d) zero

3. Above Curie temperature, a ferromagnet becomes

- (a) diamagnetic
- (b) paramagnetic
- (c) superconductor
- (d) stronger

4. Magnetic field lines

- (a) cross each other
- (b) are closed loops
- (c) start from S
- (d) end in space

5. Torque on a bar magnet in field B is

- (a) $mB \cos\theta$
- (b) $mB \sin\theta$
- (c) mB
- (d) m/B

6. Curie law: susceptibility of paramagnet $\propto$

- (a) T
- (b) $1/T$
- (c) T^2
- (d) $\sqrt{T}$

7. Soft iron is used in electromagnets because it has

- (a) high retentivity
- (b) low permeability
- (c) high permeability
- (d) high coercivity and low retentivity

8. Relative permeability of a paramagnetic material is

- (a) < 1
- (b) slightly > 1
- (c) $\gg 1$
- (d) zero

Answer key: 1-(c) Negative susceptibility. | 2-(c) Weakly repelled. | 3-(b) Domains break up. | 4-(b) No monopoles. | 5-(b) $\tau = m \times B$. | 6-(b) $\chi = C/T$. | 7-(c) Magnetises and demagnetises easily. | 8-(b) Weak attraction.

06 Electromagnetic Induction

Class XII · Unit IV

In simple words

- **Faraday's laws:** when magnetic flux through a coil changes, an emf is induced. Its size = rate of change of flux.
- **Lenz's law:** the induced current always opposes the cause that produces it (the minus sign). It follows energy conservation.
- **Self-induction:** a changing current in a coil induces emf in the same coil (L).
- **Mutual induction:** changing current in one coil induces emf in a nearby coil (M). Basis of transformers.

Remember in one line

- | | |
|---|--|
| 1 Changing flux induces an emf (Faraday). | 2 Faster change $\Rightarrow$ bigger emf. |
| 3 Induced current opposes its cause (Lenz) — energy conservation. | 4 Rod moving in B : $e = Blv$. |
| 5 Self-induction opposes change of current in the same coil. | 6 Mutual induction is the working principle of transformers. |

Theory in detail

Magnetic flux

Magnetic flux through a surface is the number of magnetic field lines passing through it: $\phi = BA \cos\theta$, where θ is the angle between B and the normal to the surface. Unit: weber (Wb) = T m^2 . Flux is maximum when the surface faces the field ($\theta = 0$) and zero when it is parallel to the field.

Induced emf vs induced current

An **emf** is induced whenever flux changes, whether the circuit is closed or open. A **current** flows only if the circuit is closed; its value depends on the resistance, $I = e/R$. Faster change of flux gives larger emf — that is why moving a magnet quickly gives a bigger deflection.

Applications

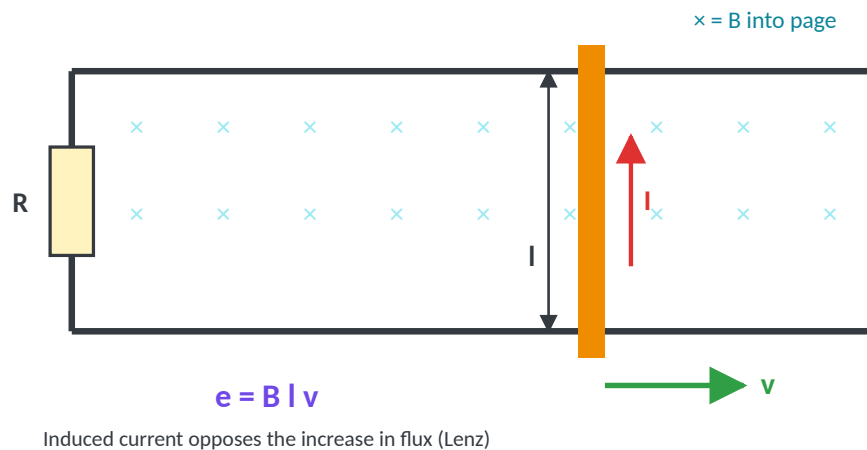
EMI is the principle of AC generators, transformers, induction cooktops, metal detectors, electric guitars' pickups, wireless phone chargers and magnetic braking in trains. Almost all electrical energy we use is produced by electromagnetic induction.

Methods of producing induced emf

Flux $\phi = BA \cos\theta$ can be changed in three ways: (1) by changing B — moving a magnet or varying current in a nearby coil; (2) by changing area A — moving a rod on rails or changing the shape of a loop; (3) by changing θ — rotating a coil in a field (AC generator). Each gives an induced emf as long as the change continues.

Self and mutual induction in daily life

When a switch in a circuit with a large inductor (fan, tube-light choke) is opened, a large self-induced emf can cause a spark. Mutual induction is used in transformers, induction coils and wireless chargers. Two coils have large mutual inductance when they are close, coaxial and wound on the same soft iron core.



 **Fig. 6.1: Motional emf: a rod sliding on rails in a magnetic field**

More theory - explained

- **Faraday's experiments:** (1) moving a magnet near a coil, (2) moving a current-carrying coil near another, (3) switching current on/off in a nearby coil — all produce a galvanometer deflection only while the flux is changing.
- **Flux** $\phi = BA \cos\theta$ (weber). It can be changed by changing B , A or θ .
- **Lenz's law example:** when a N pole approaches a coil, the near face becomes N and repels it; we must do work, which becomes electrical energy — so Lenz's law follows energy conservation.
- **Motional emf:** a rod of length l moving with v in B sweeps area at rate $lv \Rightarrow e = Blv$. Also from force qvB on free charges.
- **Rotating rod** (length L , angular speed ω): $e = \frac{1}{2}B\omega L^2$.
- **Eddy currents:** loops of current in bulk metal. Useful — electromagnetic damping in galvanometers, braking in trains, induction furnaces, speedometers. Harmful — heat in cores; reduced by laminating.
- **Self-inductance** of a solenoid: $L = \mu_0 n^2 A l = \mu_0 N^2 A / l$. The induced 'back emf' opposes change of current — inductance is like electrical inertia.
- **Mutual inductance** of two coaxial solenoids: $M = \mu_0 n_1 n_2 A l$. Depends on geometry, distance, orientation and core; $M = k\sqrt{L_1 L_2}$.
- **Charge flowing** due to induction: $q = N\Delta\phi/R$ (does not depend on time).

Key formulas

$$\phi = BA \cos\theta$$

$$e = -N \frac{d\phi}{dt}$$

$$\text{Moving rod: } e = Blv$$

$$e = -L \, dI/dt; \, e_2 = -M \, dI_1/dt$$

$$\text{Energy in inductor} = \frac{1}{2}LI^2$$

⚡ Quick 1-mark questions

Unit of inductance?

henry (Wb/A)

Why are transformer cores laminated?

To reduce eddy currents

Lenz's law is a result of?

Conservation of energy

📎 Solved problems (9)

Q1 A 100-turn coil's flux falls from 0.05 Wb to 0 in 0.1 s. Find the induced emf.

$$1. \, e = N \, \Delta\phi/\Delta t = 100 \times 0.05/0.1$$

✓ Answer: $e = 50 \, \text{V}$

Q2 A 0.5 m rod moves at 10 m/s perpendicular to a 0.4 T field. Find the emf across its ends.

$$1. \, e = Blv = 0.4 \times 0.5 \times 10$$

✓ Answer: $e = 2 \, \text{V}$

Q3 Current in a 0.2 H coil drops from 5 A to 0 in 0.01 s. Find the self-induced emf.

$$1. \, e = L \, \Delta I/\Delta t = 0.2 \times 5/0.01$$

✓ Answer: $e = 100 \, \text{V}$

Q4 A 200-turn coil ($A = 0.01 \, \text{m}^2$, $R = 10 \, \Omega$) is in B that falls from 0.5 T to 0 in 0.05 s. Find emf, current and charge.

$$1. \, e = NA\Delta B/\Delta t = 200 \times 0.01 \times 0.5/0.05 = 20 \, \text{V}$$

$$2. \, I = 20/10 = 2 \, \text{A}$$

$$3. \, q = I \times t = 2 \times 0.05$$

✓ Answer: 20 V, 2 A, 0.1 C

Q5 Find L of a solenoid of 500 turns, length 0.5 m, area $10^{-3} \, \text{m}^2$.

$$1. \, L = \mu_0 N^2 A/l = 4\pi \times 10^{-7} \times 2.5 \times 10^5 \times 10^{-3}/0.5$$

✓ Answer: $\approx 6.3 \times 10^{-4} \, \text{H}$

Q6 Find the energy stored in a 2 H inductor carrying 3 A.

$$1. \, U = \frac{1}{2}LI^2 = \frac{1}{2} \times 2 \times 9$$

✓ Answer: 9 J

Q7 $M = 0.5 \text{ H}$. Current in the primary rises from 0 to 10 A in 0.2 s. Find emf in the secondary.

1. $e = M \Delta I / \Delta t = 0.5 \times 10 / 0.2$

✓ Answer: 25 V

Q8 A 1 m rod rotates at 10 rad/s about one end in $B = 0.2 \text{ T}$. Find emf between its ends.

1. $e = \frac{1}{2} B \omega L^2 = \frac{1}{2} \times 0.2 \times 10 \times 1$

✓ Answer: 1 V

Q9 A plane with 20 m wingspan flies at 250 m/s where vertical $B = 4 \times 10^{-5} \text{ T}$. Find emf across the wings.

1. $e = Blv = 4 \times 10^{-5} \times 20 \times 250$

✓ Answer: 0.2 V

Long answer questions (5 marks)

L1 State Faraday's and Lenz's laws. Show that Lenz's law is a consequence of conservation of energy.

Answer:

1. **Faraday's 1st law:** whenever magnetic flux linked with a circuit changes, an emf is induced in it.
2. **Faraday's 2nd law:** magnitude of induced emf = rate of change of flux: $e = -N d\phi/dt$.
3. **Lenz's law:** the direction of induced current is such that it opposes the change in flux that produced it (hence the minus sign).
4. **Energy argument:** push a N pole towards a coil. The coil's near face becomes N and repels the magnet; we must do work to push it. This mechanical work appears as electrical energy (heat in the coil).
5. If the face became S instead, it would attract the magnet, speeding it up and producing current without any work — a perpetual-motion machine, which violates energy conservation.

★ Lenz's law is nature's way of conserving energy.

L2 Derive the expression for the self-inductance of a long solenoid and the energy stored in an inductor.

Answer:

1. A solenoid of length l , area A and N turns ($n = N/l$) carries current I . Field inside $B = \mu_0 n I$.
2. Total flux linked: $N\phi = N(BA) = (nl)(\mu_0 n I)A = \mu_0 n^2 A l I$.
3. $N\phi = LI \Rightarrow L = \mu_0 n^2 A l = \mu_0 N^2 A / l$. With a core of relative permeability μ_r , $L = \mu_r \mu_0 n^2 A l$.
4. **Energy:** to increase current against back emf $e = L dI/dt$, work $dW = e I dt = LI dI$.
5. $W = \int_0^I LI dI = \frac{1}{2} LI^2$, stored in the magnetic field.

★ An inductor stores energy in its magnetic field, just as a capacitor stores it in its electric field.

✓ Multiple choice questions (MCQs)

1. SI unit of magnetic flux is

- (a) tesla
- (b) weber
- (c) henry
- (d) gauss

2. Lenz's law is a consequence of conservation of

- (a) charge
- (b) momentum
- (c) energy
- (d) mass

3. Induced emf in a rod of length l moving at v in B is

- (a) Bl/v
- (b) Blv
- (c) Bv/l
- (d) B/lv

4. SI unit of inductance is

- (a) henry
- (b) weber
- (c) tesla
- (d) farad

5. Energy stored in an inductor is

- (a) LI
- (b) $\frac{1}{2}LI^2$
- (c) L^2I
- (d) $\frac{1}{2}L^2I$

6. Eddy currents are reduced by using

- (a) solid core
- (b) laminated core
- (c) copper core
- (d) air core only

7. Induced emf $e =$

- (a) $N d\phi/dt$
- (b) $-N d\phi/dt$
- (c) $N\phi$
- (d) ϕ/N

8. Self-inductance of a solenoid depends on

- (a) current
- (b) number of turns and area
- (c) voltage
- (d) time

Answer key: 1-(b) $\phi = BA$. | 2-(c) No free energy. | 3-(b) Motional emf. | 4-(a) $1 \text{ H} = 1 \text{ Wb/A}$. | 5-(b) Standard result. | 6-(b) Breaks current paths. | 7-(b) Faraday + Lenz. | 8-(b) $L = \mu_0 N^2 A/l$.



In simple words

- **AC** changes direction periodically: $I = I_0 \sin \omega t$. Meters read **rms** values.
- **Reactance**: opposition by inductor ($X_L = \omega L$) and capacitor ($X_C = 1/\omega C$). Total opposition = **impedance** Z .
- In an LCR circuit, **resonance** happens when $X_L = X_C$; then $Z = R$ and current is maximum.
- **Power factor** $\cos \phi = R/Z$. Current with no power consumed ($\phi = 90^\circ$) is called **wattless current**.
- **AC generator** turns mechanical energy into electrical energy using induction. **Transformer** steps voltage up or down (works only on AC).



Remember in one line

- | | |
|--|---|
| 1 AC changes direction periodically; meters show rms values. | 2 $I_{\text{rms}} = I_0/\sqrt{2}$ (220 V rms $\Rightarrow$ 311 V peak). |
| 3 Inductor opposes AC more at high frequency; capacitor less. | 4 At resonance $X_L = X_C$, $Z = R$, current is maximum. |
| 5 Power = $V_{\text{rms}} I_{\text{rms}} \cos \phi$; $\cos \phi$ is the power factor. | 6 Transformer steps voltage up or down (AC only). |



Theory in detail

Why AC is preferred

AC voltage can be easily stepped up or down with transformers, so power can be sent over long distances at high voltage with small losses and then reduced for homes. AC generators are simpler and cheaper, and AC can be converted to DC when needed. However, AC at high voltage is more dangerous since it reaches a peak of $\sqrt{2}$ times the rms value.

Phasors

A **phasor** is a rotating arrow whose length equals the peak value and which rotates anticlockwise with angular speed ω . Its projection on the vertical axis gives the instantaneous value. Phasors make it easy to add voltages that are out of phase in AC circuits — just add the arrows like vectors.

Impedance

Impedance Z is the total opposition to AC in a circuit containing R , L and C . It combines resistance and reactance, but not by simple addition, because their voltages are out of phase: $Z = \sqrt{R^2 + (X_L - X_C)^2}$. Unit ohm. X_L increases with frequency, X_C decreases with frequency.

Peak and rms values

AC keeps changing between $+I_0$ and $-I_0$. The **rms (root mean square) value** is the steady DC that would produce the same heat in a resistor: $I_{\text{rms}} = I_0/\sqrt{2} \approx 0.707I_0$. AC ammeters and voltmeters

read rms values. Our 220 V mains is an rms value; its peak is about 311 V.

AC generator

An AC generator (dynamo) converts mechanical energy into electrical energy by rotating a coil in a magnetic field. As the coil turns, the flux through it changes continuously, giving $e = NBA\omega \sin\omega t$. Slip rings and carbon brushes connect the rotating coil to the outer circuit. In power stations the coil is rotated by turbines driven by steam, water or wind.

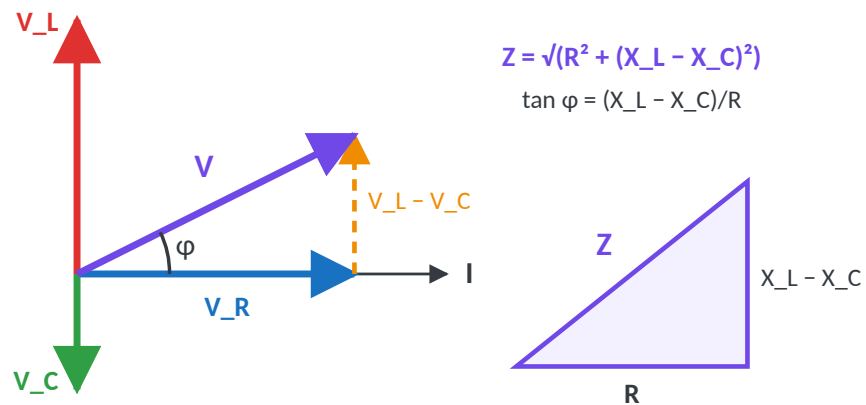


 Fig. 7.1: Phasor diagram of a series LCR circuit and the impedance triangle

More theory - explained

- **Mean and rms:** over half a cycle $I_{\text{mean}} = 0.637 I_0$; over a full cycle mean = 0. rms: average of $I^2 = I_0^2/2 \Rightarrow I_{\text{rms}} = 0.707 I_0$.
- **Pure R:** V and I in phase. **Pure L:** I lags V by 90° , $X_L = \omega L$ (zero for DC). **Pure C:** I leads V by 90° , $X_C = 1/\omega C$ (infinite for DC — blocks DC).
- **Phasor diagram (LCR):** V_R along I , V_L up, V_C down $\Rightarrow V = \sqrt{V_R^2 + (V_L - V_C)^2}$.
- **Resonance:** at $\omega_0 = 1/\sqrt{LC}$, $X_L = X_C$, $Z = R$ (minimum), current maximum, V and I in phase. Used in radio/TV tuning.
- **Quality factor** $Q = \omega_0 L/R = (1/R)\sqrt{L/C}$ — higher Q means sharper resonance.
- **Power:** $P = V_{\text{rms}} I_{\text{rms}} \cos\phi$. Pure R: $\cos\phi = 1$. Pure L or C: $\cos\phi = 0$, no power used. The component $I_{\text{rms}} \sin\phi$ is the **wattless current**. A choke coil controls current with almost no power loss.
- **AC generator:** a coil rotates in B ; $e = NBA\omega \sin\omega t$, peak $e_0 = NBA\omega$. Parts: armature coil, field magnets, slip rings, carbon brushes.
- **Transformer:** works on mutual induction. Losses: copper (use thick wires), eddy currents (laminated core), hysteresis (soft iron core), flux leakage (winding one over the other).
- **Power transmission:** sending power at high voltage makes current small, so $I^2 R$ loss in lines becomes very small.

Key formulas

$$I_{\text{rms}} = I_0/\sqrt{2}, V_{\text{rms}} = V_0/\sqrt{2}$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2}; \tan\phi = (X_L - X_C)/R$$

$$f_0 = 1/(2\pi\sqrt{LC})$$

$$P = V_{\text{rms}} I_{\text{rms}} \cos\phi$$

$$V_s/V_p = N_s/N_p = I_p/I_s$$

Quick 1-mark questions

Why can't an MCG measure AC?

Average of AC over a cycle is zero

Does a transformer work on DC?

No

Power used by an ideal inductor in AC?

Zero

Solved problems (11)

Q1 Household supply is 220 V (rms). Find the peak voltage.

$$1. V_0 = \sqrt{2} \times V_{\text{rms}} = 1.414 \times 220$$

✓ Answer: $V_0 \approx 311 \text{ V}$

Q2 Series LCR: $R = 30 \Omega$, $X_L = 80 \Omega$, $X_C = 40 \Omega$, $V_{\text{rms}} = 100 \text{ V}$. Find Z , I , power factor and power.

$$1. Z = \sqrt{30^2 + 40^2} = 50 \Omega$$

$$2. I = V/Z = 100/50 = 2 \text{ A}$$

$$3. \cos\phi = R/Z = 30/50 = 0.6$$

$$4. P = VI \cos\phi = 100 \times 2 \times 0.6$$

✓ Answer: $Z = 50 \Omega$, $I = 2 \text{ A}$, $\cos\phi = 0.6$, $P = 120 \text{ W}$

Q3 Find the resonant frequency for $L = 0.1 \text{ H}$ and $C = 10 \mu\text{F}$.

$$1. LC = 0.1 \times 10^{-5} = 10^{-6} \Rightarrow \sqrt{LC} = 10^{-3}$$

$$2. f_0 = 1/(2\pi \times 10^{-3})$$

✓ Answer: $f_0 \approx 159 \text{ Hz}$

Q4 A transformer has 500 primary and 50 secondary turns. Input is 220 V. Find output.

$$1. V_s = V_p N_s/N_p = 220 \times 50/500$$

✓ Answer: $V_s = 22 \text{ V}$ (step-down)

Q5 Find X_L for 0.5 H at 50 Hz and the current from 220 V AC.

$$1. X_L = 2\pi fL = 2 \times 3.14 \times 50 \times 0.5 \approx 157 \Omega$$

$$2. I = 220/157$$

✓ Answer: 157Ω , $\approx 1.4 \text{ A}$

Q6 Find X_C for $10\ \mu\text{F}$ at $50\ \text{Hz}$.

1. $X_C = 1/(2\pi fC) = 1/(2 \times 3.14 \times 50 \times 10^{-5})$

✓ Answer: $\approx 318\ \Omega$

Q7 Find Q-factor for $L = 0.1\ \text{H}$, $C = 10\ \mu\text{F}$, $R = 10\ \Omega$.

1. $Q = (1/R)\sqrt{L/C} = (1/10)\sqrt{(0.1/10^{-5})} = (1/10) \times 100$

✓ Answer: $Q = 10$

Q8 A 100-turn coil of area $0.1\ \text{m}^2$ rotates at $50\ \text{rev/s}$ in $B = 0.1\ \text{T}$. Find peak emf.

1. $\omega = 2\pi \times 50 = 314\ \text{rad/s}$

2. $e_0 = NBA\omega = 100 \times 0.1 \times 0.1 \times 314$

✓ Answer: $314\ \text{V}$

Q9 A transformer takes $5\ \text{A}$ at $220\ \text{V}$ and gives $9\ \text{A}$ at $110\ \text{V}$. Find its efficiency.

1. $P_{\text{in}} = 1100\ \text{W}$, $P_{\text{out}} = 990\ \text{W}$

2. $\eta = 990/1100$

✓ Answer: 90%

Q10 $10\ \text{kW}$ is sent through a line of $1\ \Omega$ at (a) $200\ \text{V}$ (b) $20\ \text{kV}$. Find line loss.

1. (a) $I = 50\ \text{A} \Rightarrow I^2R = 2500\ \text{W}$

2. (b) $I = 0.5\ \text{A} \Rightarrow I^2R = 0.25\ \text{W}$

✓ Answer: $2500\ \text{W}$ vs $0.25\ \text{W}$

Q11 An LCR circuit is at resonance. What is its power factor?

1. At resonance $Z = R \Rightarrow \cos\phi = R/Z = 1$

✓ Answer: 1 (unity)



Long answer questions (5 marks)

L1 Analyse a series LCR circuit using a phasor diagram. Derive expressions for impedance, phase angle and resonant frequency.

Answer:

1. $v = v_m \sin \omega t$ is applied to R , L , C in series; the same current $i = i_m \sin(\omega t + \phi)$ flows in all.

2. Voltage amplitudes: $V_R = i_m R$ (in phase with i), $V_L = i_m X_L$ (leads i by 90°), $V_C = i_m X_C$ (lags i by 90°).

3. V_L and V_C are opposite; net $(V_L - V_C)$ is perpendicular to V_R . So $v_m^2 = V_R^2 + (V_L - V_C)^2$.

4. $\Rightarrow Z = \sqrt{R^2 + (X_L - X_C)^2}$, $i_m = v_m/Z$; $\tan\phi = (X_L - X_C)/R$.

5. **Resonance:** $X_L = X_C \Rightarrow \omega_0 L = 1/\omega_0 C \Rightarrow \omega_0 = 1/\sqrt{LC}$, $f_0 = 1/2\pi\sqrt{LC}$. Then $Z = R$ (minimum), current is maximum, $\phi = 0$.

★ Resonance is used to select one station in radio and TV receivers.

L2 Explain the principle, construction and working of a transformer. Mention the energy losses.

Answer:

1. **Principle:** mutual induction — changing current in one coil induces emf in a nearby coil.
2. **Construction:** two coils (primary N_p and secondary N_s turns) wound on a laminated soft iron core.
3. **Working:** AC in primary produces changing flux ϕ in the core, linking both coils. $e_p = -N_p d\phi/dt$, $e_s = -N_s d\phi/dt \Rightarrow V_s/V_p = N_s/N_p$.
4. Ideal transformer: $V_p I_p = V_s I_s \Rightarrow I_s/I_p = N_p/N_s$. Step-up: $N_s > N_p$ (voltage up, current down); step-down: opposite.
5. **Losses:** flux leakage, copper ($I^2 R$) loss, eddy current loss (laminated core), hysteresis loss (soft iron), humming. Efficiency of large transformers is 95–99%.

★ Transformers make long-distance power transmission economical.

✓ Multiple choice questions (MCQs)

1. rms value of AC with peak I_0 is

- (a) I_0 (b) $I_0/2$
(c) $I_0/\sqrt{2}$ (d) $\sqrt{2} I_0$

2. In a pure inductor, current

- (a) leads V by 90° (b) lags V by 90°
(c) is in phase (d) lags by 180°

3. Capacitive reactance is

- (a) ωC (b) $1/\omega C$
(c) ωL (d) R

4. At resonance in series LCR, impedance is

- (a) maximum (b) zero
(c) R (d) X_L

5. Power factor of a purely resistive circuit is

- (a) 0 (b) 0.5
(c) 1 (d) infinite

6. Wattless current flows in a circuit with

- (a) pure R (b) pure L or C
(c) R and L (d) R and C

7. A step-up transformer increases

- (a) current (b) voltage
(c) power (d) frequency

8. Resonant frequency of LC circuit is

- (a) $1/(2\pi\sqrt{LC})$ (b) $2\pi\sqrt{LC}$
(c) $\sqrt{L/C}$ (d) LC

Answer key: 1-(c) $0.707 I_0$. | 2-(b) $X_L = \omega L$. | 3-(b) $X_C = 1/\omega C$. | 4-(c) $X_L = X_C$. | 5-(c) $\phi = 0$. | 6-(b) $\cos\phi = 0$. | 7-(b) $N_s > N_p$. | 8-(a) Standard result.

08 Electromagnetic Waves

Class XII • Unit V

In simple words

- Maxwell said a changing electric field also makes a magnetic field. The current linked with it is called **displacement current**.
- **EM waves** are made of oscillating E and B fields, perpendicular to each other and to the direction of travel (**transverse**).
- They need no medium and travel in vacuum at $c = 3 \times 10^8$ m/s.
- **Spectrum** (long $\lambda \rightarrow$ short λ): Radio $\rightarrow$ Microwave $\rightarrow$ Infrared $\rightarrow$ Visible $\rightarrow$ UV $\rightarrow$ X-rays $\rightarrow$ Gamma rays.
- **Uses**: radio – broadcasting; microwave – radar, ovens; IR – remote control, heating; visible – sight; UV – sterilising; X-rays – medical imaging; gamma – cancer treatment.

Remember in one line

- | | |
|---|--|
| 1 A changing E-field makes displacement current. | 2 EM waves are made by accelerated charges. |
| 3 E and B are perpendicular to each other and to the direction of travel. | 4 They travel at 3×10^8 m/s in vacuum and need no medium. |
| 5 Order: radio, micro, IR, visible, UV, X, gamma (λ decreasing). | 6 $E_0 = cB_0$. |

Theory in detail

Need for displacement current

Ampere's law gives inconsistent results for a charging capacitor: a surface through the wire has current, but a surface through the gap has none, though B around both loops is the same. Maxwell solved this by saying a **changing electric field** acts like a current, called displacement current $I_d = \epsilon_0 d\phi_E/dt$. This completed the laws of electromagnetism.

How an EM wave sustains itself

A changing electric field creates a changing magnetic field, which in turn creates a changing electric field, and so on. The two keep producing each other and the disturbance travels through space — even through vacuum — as an electromagnetic wave. Light itself is an EM wave, which Maxwell confirmed by calculating $c = 1/\sqrt{(\mu_0\epsilon_0)} = 3 \times 10^8$ m/s.

Transverse nature

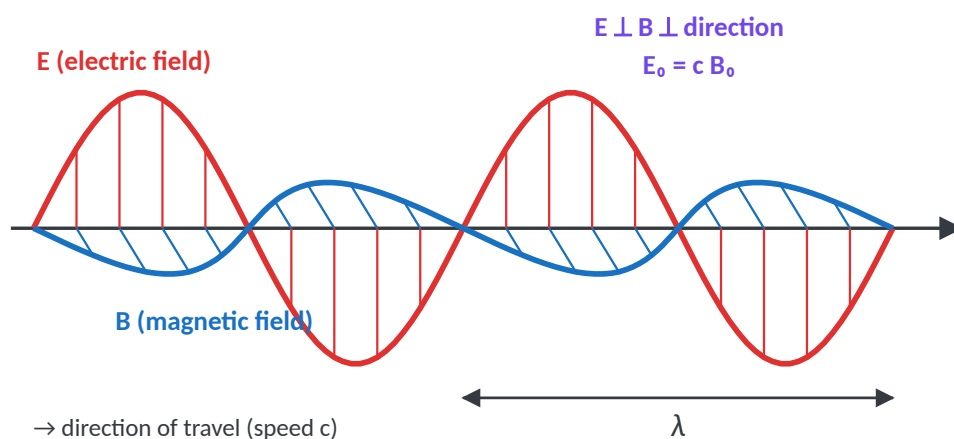
In an EM wave, E and B oscillate perpendicular to each other and both are perpendicular to the direction of travel. So EM waves are **transverse**. This is why light can be polarised, while sound (longitudinal) cannot.

Energy and momentum of EM waves

EM waves carry energy — sunlight warms us and powers plants. They also carry momentum, so they exert a tiny pressure (radiation pressure) on surfaces they hit. The pull of sunlight's pressure pushes comet tails away from the Sun. Energy is shared equally between the electric and magnetic fields.

Uses in communication

Radio waves (AM, FM), TV signals, mobile phone signals (microwaves), Wi-Fi and satellite links are all EM waves. Different frequency bands are allotted to different services so they do not interfere. Optical fibres carry data using infrared and visible light.



 **Fig. 8.1: An electromagnetic wave: E and B oscillate at right angles, in phase**

More theory - explained

- **Ampere-Maxwell law:** $\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0(I_c + I_d)$. In a charging capacitor, displacement current in the gap equals the conduction current in the wires — so current is continuous.
- **Source of EM waves:** accelerated (oscillating) charges. Frequency of the wave = frequency of the oscillating charge.
- **History:** Maxwell predicted (1864), Hertz produced them (1887), J.C. Bose made 5–25 mm waves, Marconi sent radio signals over long distances.
- **Wave equations:** $E_x = E_0 \sin(kz - \omega t)$, $B_y = B_0 \sin(kz - \omega t)$. E and B are in phase and $\perp$ each other and to the direction of travel.
- **Properties:** speed c in vacuum, c/n in a medium; carry energy and momentum (radiation pressure); $E_0 = cB_0$; energy is shared equally by E and B fields; not deflected by electric or magnetic fields.
- **Spectrum with λ range and source:** Radio (> 0.1 m, LC circuits) • Microwave (0.1 m–1 mm, klystron/magnetron) • Infrared (1 mm–700 nm, hot bodies) • Visible (700–400 nm) • UV (400–1 nm, Sun, arcs) • X-rays (1 nm– 10^{-3} nm, X-ray tube) • Gamma ($< 10^{-3}$ nm, nuclei).
- **Environment:** IR causes the greenhouse effect (keeps Earth warm); ozone layer absorbs harmful UV.

$$I_d = \epsilon_0 d\phi_E/dt$$

$$c = 1/\sqrt{(\mu_0\epsilon_0)}$$

$$c = f\lambda$$

$$E_0/B_0 = c$$

⚡ Quick 1-mark questions

Waves used in radar?

Microwaves

Waves used to kill germs?

Ultraviolet

Which EM wave has the highest frequency?

Gamma rays

✎ Solved problems (7)

Q1 An FM station broadcasts at 100 MHz. Find its wavelength.

$$1. \lambda = c/f = 3 \times 10^8 / 10^8$$

✓ Answer: $\lambda = 3 \text{ m}$ (radio wave)

Q2 In an EM wave $E_0 = 300 \text{ V/m}$. Find B_0 .

$$1. B_0 = E_0/c = 300 / 3 \times 10^8$$

✓ Answer: $B_0 = 10^{-6} \text{ T}$

Q3 A microwave oven uses 2.45 GHz. Find the wavelength.

$$1. \lambda = c/f = 3 \times 10^8 / 2.45 \times 10^9$$

✓ Answer: $\approx 12.2 \text{ cm}$

Q4 Find the frequency of X-rays of $\lambda = 1 \text{ nm}$.

$$1. f = c/\lambda = 3 \times 10^8 / 10^{-9}$$

✓ Answer: $3 \times 10^{17} \text{ Hz}$

Q5 An EM wave has $B_0 = 2 \times 10^{-8} \text{ T}$ and $f = 2 \times 10^{10} \text{ Hz}$. Find E_0 and λ .

$$1. E_0 = cB_0 = 3 \times 10^8 \times 2 \times 10^{-8} = 6 \text{ V/m}$$

$$2. \lambda = c/f = 1.5 \times 10^{-2} \text{ m}$$

✓ Answer: 6 V/m ; 1.5 cm

Q6 A capacitor is charged by a steady current of 0.15 A. Find the displacement current between its plates.

$$1. I_d = I_c \text{ (current is continuous)}$$

✓ Answer: 0.15 A

Q7 Find the speed of EM waves in glass of $n = 1.5$.

1. $v = c/n = 3 \times 10^8 / 1.5$

✓ **Answer:** $2 \times 10^8 \text{ m/s}$

Long answer questions (5 marks)

L1 What is displacement current? Show that it is equal to the conduction current in a charging capacitor.

Answer:

1. Displacement current is the current due to a changing electric field: $I_d = \epsilon_0 d\phi_E/dt$.
2. A parallel plate capacitor (plate area A) is being charged; at an instant charge is q . Field in the gap $E = q/(\epsilon_0 A)$.
3. Electric flux $\phi_E = EA = q/\epsilon_0$.
4. $I_d = \epsilon_0 d(q/\epsilon_0)/dt = dq/dt = I_c$.
5. So $I_d = I_c$: current is continuous through the wire (conduction) and the gap (displacement).
Modified Ampere's law: $\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0(I_c + I_d)$.

★ **Displacement current completes Maxwell's equations and predicts EM waves.**

L2 State the characteristics of EM waves and describe the electromagnetic spectrum with uses.

Answer:

1. **Characteristics:** produced by accelerated charges; need no medium; transverse; E and B in phase and mutually perpendicular; speed $c = 1/\sqrt{\mu_0\epsilon_0}$ in vacuum; $E_0/B_0 = c$; carry energy and momentum; not deflected by electric or magnetic fields.
2. **Radio waves** ($> 0.1 \text{ m}$): radio, TV, mobile communication.
3. **Microwaves** ($0.1 \text{ m} - 1 \text{ mm}$): radar, microwave ovens, satellite communication.
4. **Infrared** ($1 \text{ mm} - 700 \text{ nm}$): remote controls, night vision, physiotherapy, greenhouse effect.
5. **Visible** ($700 - 400 \text{ nm}$): seeing; photosynthesis. **Ultraviolet** ($400 - 1 \text{ nm}$): sterilising water and instruments, detecting forged notes; mostly absorbed by ozone.
6. **X-rays** ($1 - 10^{-3} \text{ nm}$): medical imaging, studying crystals. **Gamma rays** ($< 10^{-3} \text{ nm}$): cancer treatment, nuclear studies.

★ **All EM waves differ only in wavelength (or frequency).**

✓ Multiple choice questions (MCQs)

1. EM waves are

- (a) longitudinal
- (b) transverse
- (c) mechanical
- (d) stationary

2. Speed of EM waves in vacuum is

- (a) 3×10^6 m/s
- (b) 3×10^8 m/s
- (c) 3×10^{10} m/s
- (d) 340 m/s

3. Which has the shortest wavelength?

- (a) X-rays
- (b) UV
- (c) Gamma rays
- (d) Radio

4. Radiation used in remote controls is

- (a) UV
- (b) infrared
- (c) microwave
- (d) X-ray

5. Radar uses

- (a) radio waves
- (b) microwaves
- (c) infrared
- (d) gamma rays

6. Displacement current was introduced by

- (a) Faraday
- (b) Maxwell
- (c) Hertz
- (d) Ampere

7. Ozone layer absorbs

- (a) IR
- (b) UV
- (c) radio
- (d) visible

8. Ratio E_0/B_0 in an EM wave equals

- (a) 1
- (b) c
- (c) $1/c$
- (d) c^2

Answer key: 1-(b) E, B $\perp$ direction. | 2-(b) $c = 1/\sqrt{(\mu_0\epsilon_0)}$. | 3-(c) Highest frequency. | 4-(b) IR LEDs. | 5-(b) Short wavelength, directional. | 6-(b) Ampere–Maxwell law. | 7-(b) Protects life. | 8-(b) $E_0 = cB_0$.

09 Ray Optics and Optical Instruments

Class XII · Unit VI

In simple words

- **Sign convention:** measure distances from the pole/optical centre; along incident light = +, against = -.
- **Refraction:** light bends when going into another medium (Snell's law). **TIR** happens when light goes from denser to rarer medium at angle > critical angle (used in optical fibres).
- **Lenses:** convex (converging, f +), concave (diverging, f -). Power $P = 1/f$ (in metres), unit dioptre (D).
- **Prism** bends light; at minimum deviation the ray passes symmetrically.
- **Microscope** makes near tiny objects look big; **telescope** makes far objects look big. Reflecting telescopes use a mirror (no chromatic aberration).

Remember in one line

- | | |
|--|--|
| 1 Light bends when it enters a new medium (Snell's law). | 2 TIR happens from denser to rarer medium beyond critical angle. |
| 3 Mirror: $1/v + 1/u = 1/f$; lens: $1/v - 1/u = 1/f$. | 4 Power $P = 1/f$ (m) in dioptre; powers of lenses in contact add. |
| 5 Prism: violet bends most, red least (dispersion). | 6 Telescope $M = f_o/f_e$; microscope uses short focal lenses. |

Theory in detail

Laws of refraction

When light goes from one medium to another, it bends because its speed changes. (1) The incident ray, refracted ray and normal lie in one plane. (2) **Snell's law:** $\sin i / \sin r = n_2 / n_1$. Light bends towards the normal on entering a denser medium and away from it on entering a rarer medium. Refractive index $n = c/v$.

Optical fibres

An optical fibre is a thin glass or plastic strand with a **core** of higher refractive index surrounded by **cladding** of lower index. Light entering at a suitable angle suffers repeated total internal reflection and travels along even a bent fibre with very little loss. Uses: high-speed internet and telephone signals, endoscopy in medicine, decorative lamps.

Power of a lens and spectacles

Power $P = 1/f$ (f in metre), unit dioptre (D). Convex lens: positive power; concave: negative. A short-sighted (myopic) eye needs a concave lens; a long-sighted (hypermetropic) eye needs a convex lens. Opticians add the powers of lenses in contact to get the net power.

Spherical mirrors and mirror formula

Concave mirrors converge light and are used in torches, shaving mirrors and solar cookers; convex mirrors diverge light and give a wider field of view (rear-view mirrors). The focal length is

half the radius of curvature ($f = R/2$). The mirror formula $1/v + 1/u = 1/f$ works for both, with proper signs.

Refraction through a prism and dispersion

Light passing through a glass prism bends twice, towards the base. The angle between the incident ray and emergent ray is the **angle of deviation**. It first decreases as i increases, reaches a minimum δ_m , then increases. White light splits into seven colours (VIBGYOR) because n is different for each colour — violet bends most. This is **dispersion**, which also produces rainbows.

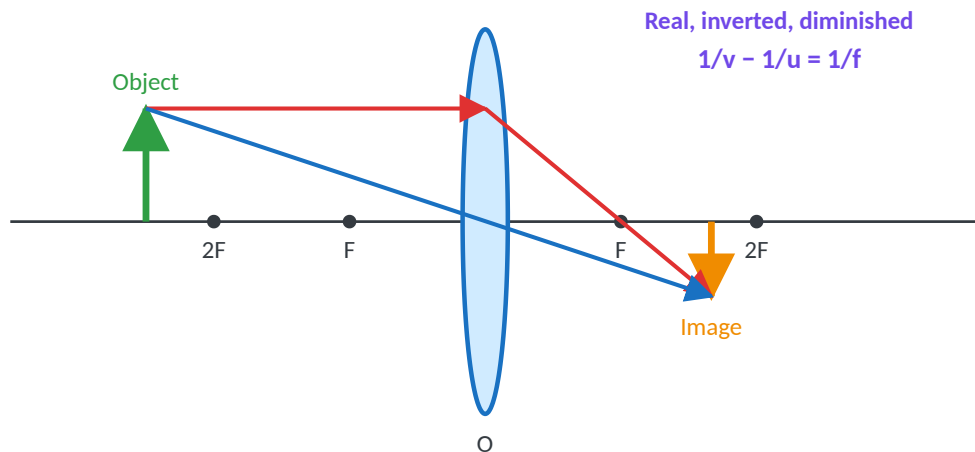


 Fig. 9.1: Image formed by a convex lens (object beyond 2F)

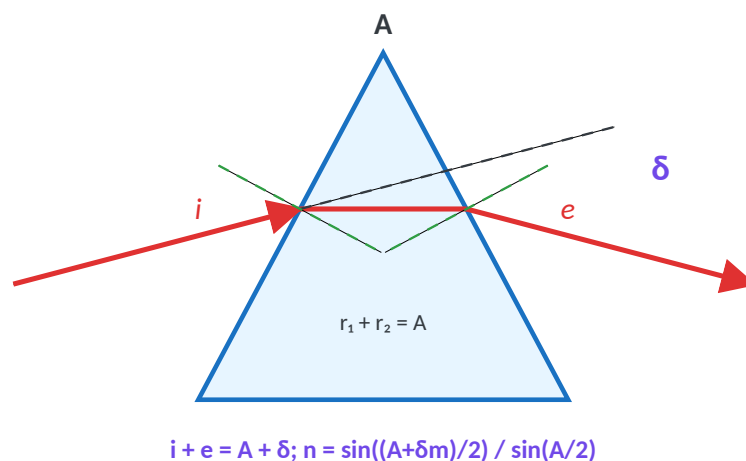


 Fig. 9.2: Refraction through a prism: angle of deviation δ

More theory - explained

- **Concave mirror images:** object beyond C $\rightarrow$ real, inverted, small; at C $\rightarrow$ same size at C; between C and F $\rightarrow$ magnified beyond C; at F $\rightarrow$ at infinity; between F and P $\rightarrow$ virtual, erect, magnified. Convex mirror always gives virtual, erect, small image.
- **Refractive index** $n_{21} = v_1/v_2$. **Apparent depth** = real depth/ n (a pool looks shallower).
- **TIR examples:** sparkling diamond ($C \approx 24^\circ$), mirage, optical fibre (core of higher n than cladding, carries light by repeated TIR), totally reflecting prisms in binoculars.

- **Refraction at a spherical surface:** $n_2/v - n_1/u = (n_2 - n_1)/R$. Applying it to both faces of a lens gives the lens maker's formula.
- **Lenses in contact:** $1/f = 1/f_1 + 1/f_2$, $P = P_1 + P_2$, $m = m_1 \times m_2$.
- **Prism:** $r_1 + r_2 = A$ and $i + e = A + \delta$. At minimum deviation $i = e$ and $r = A/2$. Thin prism $\delta = (n - 1)A$. White light splits (dispersion); violet deviates most, red least.
- **Simple microscope:** $M = 1 + D/f$ (image at $D = 25$ cm). **Compound microscope:** $M = m_o \times m_e \approx (L/f_o)(D/f_e)$; both lenses have short f , objective shorter.
- **Astronomical telescope:** $M = f_o/f_e$, length = $f_o + f_e$ (normal adjustment). Objective has large f and large aperture.
- **Reflecting telescope** (Cassegrain): uses a concave mirror — no chromatic aberration, less spherical aberration (parabolic), lighter and cheaper for large apertures.

🔑 Key formulas

Mirror: $1/v + 1/u = 1/f$; $m = -v/u$; $f = R/2$

Lens: $1/v - 1/u = 1/f$; $m = v/u$

Lens maker: $1/f = (\mu - 1)(1/R_1 - 1/R_2)$

$P = P_1 + P_2$; $\sin C = 1/\mu$

Prism: $\mu = \sin((A + \delta_m)/2) / \sin(A/2)$; Telescope $M = f_o/f_e$

🔍 Quick 1-mark questions

Why does a diamond sparkle?

Small critical angle $\Rightarrow$ repeated TIR

Does f of a mirror change in water?

No

Power of a plane glass slab?

Zero

📝 Solved problems (11)

Q1 An object is 30 cm in front of a concave mirror of $f = 10$ cm. Find image position and magnification.

1. $u = -30$, $f = -10$

2. $1/v = 1/f - 1/u = -1/10 + 1/30 = -2/30 \Rightarrow v = -15$ cm

3. $m = -v/u = -(-15)/(-30) = -0.5$

✓ Answer: Image at 15 cm in front, real, inverted, half size

Q2 An object is 30 cm from a convex lens of $f = 20$ cm. Find the image.

1. $u = -30$, $f = +20$

2. $1/v = 1/f + 1/u = 1/20 - 1/30 = 1/60 \Rightarrow v = +60$ cm

3. $m = v/u = 60/(-30) = -2$

✓ Answer: Image 60 cm behind lens, real, inverted, 2× bigger

Q3 Find the critical angle for glass ($\mu = 1.5$).

1. $\sin C = 1/\mu = 1/1.5 = 0.667$

✓ Answer: $C \approx 41.8^\circ$

Q4 A biconvex lens has $R_1 = 20$ cm, $R_2 = -20$ cm, $\mu = 1.5$. Find f and power.

1. $1/f = (1.5 - 1)(1/20 + 1/20) = 0.5 \times 0.1 = 0.05$

2. $f = 20$ cm = 0.2 m; $P = 1/0.2$

✓ Answer: $f = 20$ cm, $P = +5$ D

Q5 A tank has 12 cm of water ($n = 4/3$). How deep does it appear?

1. Apparent depth = $12/(4/3)$

✓ Answer: 9 cm

Q6 An object is 10 cm in front of a convex mirror of $f = 15$ cm. Find the image.

1. $u = -10$, $f = +15$

2. $1/v = 1/f - 1/u = 1/15 + 1/10 = 1/6 \Rightarrow v = +6$ cm

3. $m = -v/u = 0.6$

✓ Answer: 6 cm behind mirror, virtual, erect, 0.6×

Q7 Lenses of +20 cm and -30 cm are in contact. Find f and P .

1. $1/f = 1/20 - 1/30 = 1/60$

✓ Answer: $f = 60$ cm, $P \approx +1.67$ D

Q8 A prism of $A = 60^\circ$ gives $\delta_m = 30^\circ$. Find n .

1. $n = \sin((A + \delta_m)/2)/\sin(A/2) = \sin 45^\circ/\sin 30^\circ = 0.707/0.5$

✓ Answer: $n \approx 1.414$

Q9 A telescope has $f_o = 150$ cm and $f_e = 5$ cm. Find M and length.

1. $M = f_o/f_e = 30$

2. $L = 150 + 5$

✓ Answer: $M = 30$, $L = 155$ cm

Q10 Objective of a microscope magnifies 15 times; eyepiece $f = 5$ cm forms final image at 25 cm. Find total M .

1. $m_e = 1 + D/f_e = 1 + 25/5 = 6$

2. $M = 15 \times 6$

✓ Answer: 90

Q11 Light from air falls on a glass surface ($n = 1.5$, $R = +20$ cm) from an object 100 cm away. Find the image.

- $1.5/v - 1/(-100) = (1.5 - 1)/20 = 0.025$
- $1.5/v = 0.015 \Rightarrow v = 100$ cm

✓ Answer: Real image 100 cm inside glass

Long answer questions (5 marks)

L1 Derive the lens maker's formula for a thin double convex lens.

Answer:

- Lens of refractive index n_2 in a medium n_1 ; surfaces of radii R_1 and R_2 . Object O at distance u .
- First surface:** refraction forms image I_1 at v_1 : $n_2/v_1 - n_1/u = (n_2 - n_1)/R_1$.
- Second surface:** I_1 acts as object (thin lens); final image at v : $n_1/v - n_2/v_1 = (n_1 - n_2)/R_2$.
- Adding: $n_1(1/v - 1/u) = (n_2 - n_1)(1/R_1 - 1/R_2)$.
- For $u = \infty$, $v = f$: $1/f = (n_{21} - 1)(1/R_1 - 1/R_2)$, where $n_{21} = n_2/n_1$.
- Combining the two: $1/v - 1/u = 1/f$ (thin lens formula).

★ Focal length depends on the lens material and curvature of its surfaces.

L2 Explain the working of an astronomical telescope with a ray diagram description. Derive its magnifying power.

Answer:

- It has two convex lenses: **objective** of large focal length f_o and large aperture, and **eyepiece** of small focal length f_e .
- Parallel rays from a distant star form a real, inverted, small image at the focus of the objective.
- This image acts as the object for the eyepiece, which works as a magnifier. In **normal adjustment** the image is at the focus of the eyepiece too, so the final image is at infinity.
- Magnifying power $M = \beta/\alpha$, where α = angle subtended by the object ($= h/f_o$) and β = angle subtended by the final image ($= h/f_e$).
- $M = f_o/f_e$; tube length $L = f_o + f_e$. For final image at D: $M = (f_o/f_e)(1 + f_e/D)$.
- Reflecting telescopes** use a concave mirror as objective: no chromatic aberration, less spherical aberration, easier to support large mirrors.

★ Large f_o and small f_e give high magnification.

✓ Multiple choice questions (MCQs)

1. Focal length of a mirror of radius R is

- (a) R
- (b) 2R
- (c) $R/2$
- (d) $R/4$

2. Power of a lens of focal length 50 cm is

- (a) 0.5 D
- (b) 2 D
- (c) 50 D
- (d) 5 D

3. Optical fibres work on

- (a) refraction
- (b) dispersion
- (c) total internal reflection
- (d) diffraction

4. Critical angle for glass ($n = 1.5$) is about

- (a) 30°
- (b) 42°
- (c) 60°
- (d) 90°

5. Which colour deviates the most in a prism?

- (a) Red
- (b) Yellow
- (c) Green
- (d) Violet

6. Rear-view mirrors in vehicles are

- (a) concave
- (b) convex
- (c) plane
- (d) cylindrical

7. Magnifying power of a telescope in normal adjustment is

- (a) $f_o \times f_e$
- (b) f_o/f_e
- (c) f_e/f_o
- (d) $f_o + f_e$

8. A convex lens forms a virtual image when object is

- (a) beyond 2F
- (b) at F
- (c) between F and O
- (d) at 2F

Answer key: 1-(c) $f = R/2$. | 2-(b) $P = 1/0.5 \text{ m}$. | 3-(c) Repeated TIR. | 4-(b) $\sin C = 1/1.5$. | 5-(d) Largest n. | 6-(b) Wider field of view. | 7-(b) Standard result. | 8-(c) Acts as magnifier.

In simple words

- A **wavefront** is a surface where all points vibrate in the same phase.
- **Huygens' principle**: every point on a wavefront acts as a source of secondary wavelets; the new wavefront is their envelope. It proves laws of reflection and refraction.
- **Interference**: two **coherent** sources (same frequency, constant phase difference) give bright and dark fringes.
- In **YDSE**, all fringes have equal width $\beta = \lambda D/d$.
- **Diffraction**: bending of light around a small slit. The central bright band is twice as wide as the others.

Remember in one line

- | | |
|--|---|
| 1 Every point on a wavefront sends out new wavelets (Huygens). | 2 Frequency stays the same on refraction; wavelength changes. |
| 3 Coherent sources are needed for steady interference. | 4 Fringe width $\beta = \lambda D/d$; all fringes equal. |
| 5 Diffraction is the bending of light round small slits. | 6 Central maximum in single slit is twice as wide as others. |

Theory in detail

Wave nature of light

Newton thought light was made of tiny particles (corpuscles). Huygens proposed that light is a wave. Young's double slit experiment (1801) showed interference, which only waves can do, and Maxwell later proved light is an electromagnetic wave. Wave optics explains interference, diffraction and polarisation, which ray optics cannot.

Coherent sources and sustained interference

Two sources are **coherent** when they have the same frequency and a constant phase difference. Only then is the interference pattern steady (sustained). In YDSE one slit illuminates two slits, so both get light from the same wavefront and stay coherent. Two independent bulbs change phase randomly millions of times per second, so no steady pattern is seen.

Diffraction around us

Diffraction is the spreading of waves around obstacles. It is easy to notice for sound ($\lambda \sim 1$ m) — we hear people round a corner — but hard for light ($\lambda \sim 500$ nm). Colours seen in a CD, the fuzzy edge of shadows and the limit on how sharp a microscope or telescope image can be are due to diffraction of light.

Reflection using wavefronts

A plane wavefront hitting a mirror at angle i : while one end of the wavefront reaches the mirror, wavelets from the other end have already travelled the same distance back. The new tangent

(reflected wavefront) makes the same angle with the mirror. So angle of incidence = angle of reflection. Speed and wavelength are unchanged in reflection.

Width of central maximum

In single-slit diffraction, the first dark bands are at angles $\pm\lambda/a$. So the central bright band has angular width $2\lambda/a$ and linear width $2\lambda D/a$ on a screen at distance D . A narrower slit or longer wavelength gives a wider central band. If the slit is much wider than λ , diffraction becomes too small to see and light seems to travel straight.

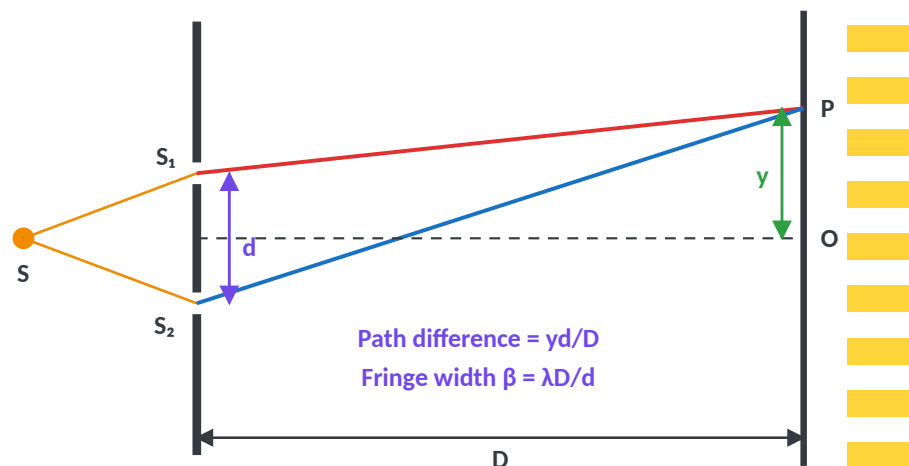


 Fig. 10.1: Young's double slit experiment

More theory - explained

- **Types of wavefront:** point source $\rightarrow$ spherical; line source $\rightarrow$ cylindrical; distant source $\rightarrow$ plane. Rays are always perpendicular to wavefronts.
- **Refraction by Huygens:** in time t the wavelet travels $BC = v_1 t$ in medium 1 and $AE = v_2 t$ in medium 2 $\Rightarrow \sin i / \sin r = v_1 / v_2 = n_{21}$ (Snell's law). Frequency stays the same; λ becomes λ/n .
- **Reflection by Huygens:** incident and reflected wavelets travel equal distances in the same time $\Rightarrow$ the two triangles are congruent $\Rightarrow i = r$.
- **Coherent sources** come from a single source (two slits lit by one slit). Two separate bulbs are never coherent because their phases change randomly.
- **Conditions for sustained interference:** coherent sources, same frequency, nearly equal amplitudes, narrow slits placed close together, screen far away.
- **Intensity:** $I_{\max} = (\sqrt{I_1} + \sqrt{I_2})^2$, $I_{\min} = (\sqrt{I_1} - \sqrt{I_2})^2$. Energy is only redistributed, not lost.
- **YDSE fringe positions:** bright $y_n = n\lambda D/d$; dark $y = (2n - 1)\lambda D/2d$. In water β becomes β/n . With white light: central fringe white, others coloured.
- **Single slit:** minima at $a \sin\theta = n\lambda$; central maximum angular width = $2\lambda/a$; secondary maxima much weaker. Diffraction is clear only when slit width $\approx \lambda$.
- **Interference vs diffraction:** interference — two sources, equal-width fringes, equal brightness; diffraction — one wavefront, central fringe twice as wide and brightest, others fade.

Key formulas

$$\text{Snell: } \sin i / \sin r = v_1/v_2 = \mu_2/\mu_1$$

$$\text{Fringe width } \beta = \lambda D/d$$

$$\text{Bright: path diff} = n\lambda; \text{ Dark: } (2n-1)\lambda/2$$

$$\text{Central maximum width} = 2\lambda D/a$$

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \phi$$

Quick 1-mark questions

Wavefront shape from a distant star?

Plane

Does frequency change on refraction?

No

Why can't two bulbs show interference?

They are not coherent

Solved problems (8)

Q1 In YDSE, $\lambda = 600 \text{ nm}$, $D = 1 \text{ m}$, $d = 0.5 \text{ mm}$. Find the fringe width.

$$1. \beta = \lambda D/d = 6 \times 10^{-7} \times 1 / 5 \times 10^{-4}$$

$$\checkmark \text{ Answer: } \beta = 1.2 \times 10^{-3} \text{ m} = 1.2 \text{ mm}$$

Q2 Light of 500 nm falls on a 0.1 mm slit. Find the width of the central maximum on a screen 1 m away.

$$1. \text{Width} = 2\lambda D/a = 2 \times 5 \times 10^{-7} \times 1 / 10^{-4}$$

$$\checkmark \text{ Answer: Width} = 10^{-2} \text{ m} = 1 \text{ cm}$$

Q3 Find the speed of light in glass ($\mu = 1.5$).

$$1. v = c/\mu = 3 \times 10^8 / 1.5$$

$$\checkmark \text{ Answer: } v = 2 \times 10^8 \text{ m/s}$$

Q4 Two waves have intensities in ratio $9 : 1$. Find $I_{\max} : I_{\min}$.

$$1. \text{Amplitude ratio} = \sqrt{9} : 1 = 3 : 1$$

$$2. I_{\max}/I_{\min} = (3 + 1)^2 / (3 - 1)^2 = 16/4$$

$$\checkmark \text{ Answer: } 4 : 1$$

Q5 In YDSE ($\lambda = 600 \text{ nm}$, $D = 1 \text{ m}$, $d = 0.5 \text{ mm}$) find the distance of the 3rd bright fringe from the centre.

$$1. y_3 = 3\lambda D/d = 3 \times 1.2 \text{ mm}$$

$$\checkmark \text{ Answer: } 3.6 \text{ mm}$$

Q6 The same YDSE is done in water ($n = 4/3$). Find the new fringe width.

1. $\beta' = \beta/n = 1.2/(4/3)$

✓ Answer: 0.9 mm

Q7 Light of 600 nm in air enters glass ($n = 1.5$). Find λ and f in glass.

1. $\lambda' = \lambda/n = 400 \text{ nm}$

2. $f = c/\lambda = 3 \times 10^8 / 6 \times 10^{-7}$ (unchanged)

✓ Answer: 400 nm; $5 \times 10^{14} \text{ Hz}$

Q8 Light of 500 nm falls on a slit of width $1 \mu\text{m}$. Find the angle of the first minimum.

1. $a \sin \theta = \lambda \Rightarrow \sin \theta = 0.5 \mu\text{m} / 1 \mu\text{m} = 0.5$

✓ Answer: $\theta = 30^\circ$

Long answer questions (5 marks)

L1 Using Huygens' principle, prove the laws of refraction at a plane surface.

Answer:

- Huygens' principle:** every point on a wavefront is a source of secondary wavelets travelling with the wave speed; the envelope of these wavelets after time t gives the new wavefront.
- Plane wavefront AB meets the surface XY at A with angle i . Speed in medium 1 is v_1 , in medium 2 is v_2 .
- While the wavelet from B travels $BC = v_1 t$ to the surface, the wavelet from A travels $AE = v_2 t$ into medium 2. The tangent CE is the refracted wavefront, making angle r with the surface.
- From triangles ABC and AEC: $\sin i = BC/AC = v_1 t/AC$ and $\sin r = AE/AC = v_2 t/AC$.
- $\sin i / \sin r = v_1 / v_2 = n_2 / n_1$ (Snell's law). Incident ray, refracted ray and normal all lie in the same plane.
- Frequency is unchanged; since $v = f\lambda$, wavelength in the denser medium is smaller: $\lambda_2 = \lambda_1 v_2 / v_1$.

★ Huygens' principle explains refraction without the idea of particles.

L2 Describe Young's double slit experiment. Write the conditions for bright and dark fringes and the expression for fringe width.

Answer:

- Monochromatic light from slit S falls on two narrow close slits S_1 and S_2 (separation d); these act as coherent sources. Screen at distance D shows alternate bright and dark bands.
- At a point P at height y on the screen, path difference $S_2P - S_1P = yd/D$ (for $D \gg d$).
- Bright fringe** (constructive): path difference $= n\lambda \Rightarrow y_n = n\lambda D/d$, $n = 0, 1, 2 \dots$

4. **Dark fringe** (destructive): path difference = $(2n - 1)\lambda/2 \Rightarrow y = (2n - 1)\lambda D/2d$.
5. **Fringe width** (distance between consecutive bright or dark fringes): $\beta = \lambda D/d$. All fringes are equally wide.
6. β increases with λ and D and decreases with d . The central fringe ($n = 0$) is always bright.

★ YDSE was the first proof of the wave nature of light.

✓ Multiple choice questions (MCQs)

1. Wavefront from a distant source is

- (a) spherical (b) cylindrical
(c) plane (d) elliptical

2. Fringe width in YDSE is

- (a) $\lambda d/D$ (b) $\lambda D/d$
(c) Dd/λ (d) λ/Dd

3. If YDSE is done in water, fringe width

- (a) increases (b) decreases
(c) stays same (d) becomes zero

4. On refraction, which does not change?

- (a) speed (b) wavelength
(c) frequency (d) direction

5. Two independent bulbs don't show interference because they are

- (a) too bright (b) not coherent
(c) white (d) far

6. Condition for bright fringe: path difference =

- (a) $n\lambda$ (b) $(2n-1)\lambda/2$
(c) $\lambda/4$ (d) zero only

7. Angular width of central maximum (single slit) is

- (a) λ/a (b) $2\lambda/a$
(c) a/λ (d) $\lambda/2a$

8. Diffraction is more noticeable when slit width is

- (a) much larger than λ (b) about λ
(c) zero (d) infinite

Answer key: 1-(c) Large radius. | 2-(b) $\beta = \lambda D/d$. | 3-(b) λ decreases. | 4-(c) Set by the source. | 5-(b) Random phases. | 6-(a) Constructive. | 7-(b) Between first minima. | 8-(b) Comparable size.

11 Dual Nature of Radiation and Matter

Class XII • Unit VII

In simple words

- **Photoelectric effect:** light of suitable frequency ejects electrons from a metal surface (Hertz, Lenard).
- Key observations: emission is instant; there is a **threshold frequency**; KE of electrons depends on frequency, not intensity; number of electrons depends on intensity.
- **Einstein:** light comes in packets called **photons** of energy hf . This proves the **particle nature** of light.
- **Work function** ϕ_0 : minimum energy needed to remove an electron.
- **de Broglie:** moving particles also behave like waves, $\lambda = h/p$.

Remember in one line

- | | |
|---|---|
| 1 Light can eject electrons from metals (photoelectric effect). | 2 Below threshold frequency, no electrons come out. |
| 3 Photon energy $E = hf$; more intensity = more photons. | 4 Einstein: $hf = \phi_0 + K_{\text{max}}$. |
| 5 Stopping potential depends on frequency, not intensity. | 6 Moving particles have waves too: $\lambda = h/mv$. |

Theory in detail

Hertz and Lenard's observations

In 1887 Hertz found that sparks jumped more easily across a gap when UV light fell on it. Lenard then showed that UV light striking a metal plate ejected negative particles (electrons) which produced a current. Hallwachs found that zinc plates lost negative charge under UV. These were the first observations of the **photoelectric effect**.

Laws of photoelectric emission

(1) For a given metal there is a minimum (**threshold**) frequency below which no emission occurs, however intense the light. (2) Photocurrent is proportional to intensity. (3) Maximum KE of electrons increases with frequency but is independent of intensity. (4) Emission is **instantaneous** (no time lag, $< 10^{-9}$ s).

Dual nature

Light behaves as a wave in interference and diffraction, but as particles (photons) in the photoelectric effect. De Broglie suggested that matter too has this dual nature. Both descriptions are needed — which one shows up depends on the experiment. The electron microscope uses the wave nature of electrons to see extremely small objects.

Effect of intensity and frequency

Increasing the **intensity** of light (same frequency) increases the number of photons, so more electrons are emitted and saturation current increases; stopping potential stays the same. Increasing the **frequency** (same intensity) increases the energy of each photon, so the maximum KE and stopping potential increase; saturation current stays nearly the same.

Photon as a particle

A photon behaves like a particle of energy $E = hf$ and momentum $p = h/\lambda$. It always moves at speed c in vacuum and has zero rest mass. Photons are not deflected by electric or magnetic fields (no charge). In a photon-electron collision, total energy and momentum are conserved, but the number of photons may change (they can be absorbed or created).

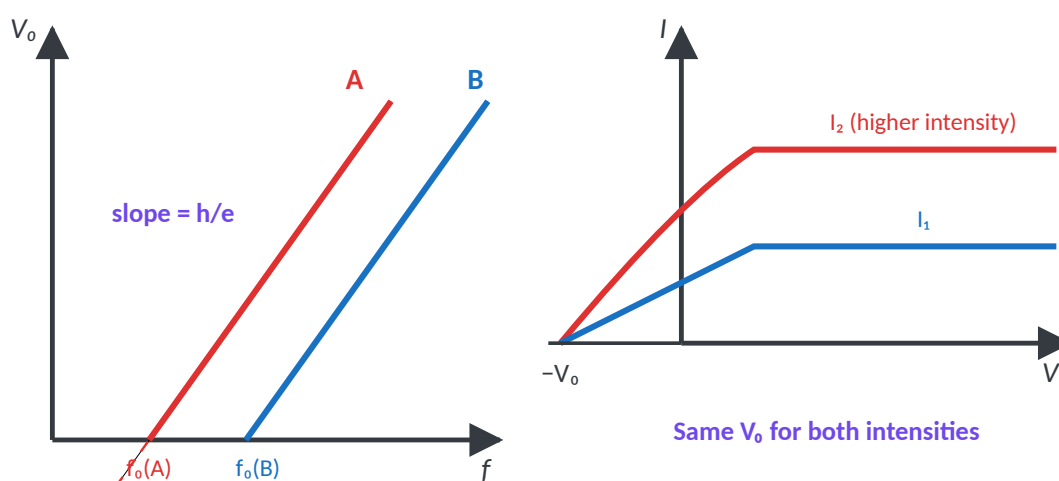


 Fig. 11.1: Stopping potential vs frequency (left) and photocurrent vs voltage (right)

More theory - explained

- **Electron emission:** thermionic (heating), field (strong electric field), photoelectric (light). Work function is lowest for caesium (≈ 2.1 eV).
- **Experimental set-up:** light falls on emitter C in an evacuated tube; collector A at variable potential; micro-ammeter measures photocurrent.
- **Graphs:** (i) current $\propto$ intensity; (ii) current vs potential — saturates for positive V , becomes zero at $-V_0$; V_0 is the same for all intensities; (iii) V_0 vs f is a straight line of slope h/e , cutting the f -axis at f_0 .
- **Why wave theory failed:** it predicts KE should rise with intensity, no threshold frequency, and a time lag for weak light — none are observed.
- **Photon picture:** $E = hf$, $p = h/\lambda$, rest mass zero, speed c . Higher intensity = more photons, not more energy per photon. Energy and momentum are conserved in photon-electron collisions.
- **Einstein's equation** $hf = \phi_0 + K_{\max}$: part of photon energy frees the electron, the rest becomes its KE.
- **de Broglie:** $\lambda = h/mv$. For a charge accelerated through V : $\lambda = h/\sqrt{(2mqV)}$. For everyday objects λ is too small to notice.
- **Davisson-Germer experiment** (electrons at 54 V diffracted by nickel crystal, $\lambda \approx 0.167$ nm) proved the wave nature of electrons.

- **Uses of photocells:** automatic doors, burglar alarms, street-light switches, light meters, solar calculators.

📌 Key formulas

$$E = hf = hc/\lambda; h = 6.63 \times 10^{-34} \text{ J s}$$

$$K_{\max} = hf - \phi_0 = eV_0$$

$$\phi_0 = hf_0$$

$$\lambda = h/p = h/\sqrt{2mK}$$

$$\text{Electron: } \lambda = 1.227/\sqrt{V} \text{ nm; } hc \approx 1240 \text{ eV nm}$$

⚡ Quick 1-mark questions

Does stopping potential depend on intensity?

No, only on frequency

Electron or proton with same KE — which has larger λ ?

Electron (smaller mass)

Rest mass of a photon?

Zero

📝 Solved problems (9)

Q1 Find the energy of a photon of wavelength 500 nm in J and eV.

$$1. E = hc/\lambda = 6.63 \times 10^{-34} \times 3 \times 10^8 / 5 \times 10^{-7} = 3.98 \times 10^{-19} \text{ J}$$

$$2. \text{In eV: } 3.98 \times 10^{-19} / 1.6 \times 10^{-19}$$

✓ Answer: $E \approx 3.98 \times 10^{-19} \text{ J} \approx 2.49 \text{ eV}$

Q2 Light of 3 eV falls on a metal with work function 2 eV. Find $K_{\max}$, stopping potential and threshold wavelength.

$$1. K_{\max} = 3 - 2 = 1 \text{ eV} \Rightarrow V_0 = 1 \text{ V}$$

$$2. \lambda_0 = hc/\phi_0 = 1240/2 \text{ nm}$$

✓ Answer: $K_{\max} = 1 \text{ eV}, V_0 = 1 \text{ V}, \lambda_0 = 620 \text{ nm}$

Q3 Find the de Broglie wavelength of an electron accelerated through 100 V.

$$1. \lambda = 1.227/\sqrt{100} \text{ nm} = 1.227/10$$

✓ Answer: $\lambda \approx 0.123 \text{ nm}$

Q4 A 10 mW laser gives light of 632.8 nm. How many photons does it emit per second?

$$1. E_{\text{photon}} = 1240/632.8 \approx 1.96 \text{ eV} \approx 3.14 \times 10^{-19} \text{ J}$$

$$2. N = P/E = 10^{-2}/3.14 \times 10^{-19}$$

✓ Answer: $\approx 3.2 \times 10^{16} \text{ per second}$

Q5 Find the threshold frequency for a metal of work function 2.3 eV.

$$1. f_0 = \phi_0/h = 2.3 \times 1.6 \times 10^{-19}/6.63 \times 10^{-34}$$

✓ Answer: $\approx 5.55 \times 10^{14} \text{ Hz}$

Q6 Find the maximum speed of photoelectrons having $K_{\max} = 1 \text{ eV}$.

1. $v = \sqrt{(2K/m)} = \sqrt{(2 \times 1.6 \times 10^{-19} / 9.1 \times 10^{-31})}$

✓ Answer: $\approx 5.9 \times 10^5 \text{ m/s}$

Q7 Find the de Broglie wavelength of a 0.1 kg ball moving at 10 m/s.

1. $\lambda = h/mv = 6.63 \times 10^{-34} / 1$

✓ Answer: $6.63 \times 10^{-34} \text{ m}$ (unobservable)

Q8 Find the momentum of a photon of 500 nm.

1. $p = h/\lambda = 6.63 \times 10^{-34} / 5 \times 10^{-7}$

✓ Answer: $\approx 1.33 \times 10^{-27} \text{ kg m/s}$

Q9 In an experiment V_0 rises by 1.5 V when f rises by $3.6 \times 10^{14} \text{ Hz}$. Find h .

1. Slope $h/e = \Delta V_0 / \Delta f$

2. $h = 1.6 \times 10^{-19} \times 1.5 / 3.6 \times 10^{14}$

✓ Answer: $\approx 6.7 \times 10^{-34} \text{ J s}$



Long answer questions (5 marks)

L1 Write Einstein's photoelectric equation and explain the laws of photoelectric effect with it.

Answer:

1. Einstein said light consists of photons, each of energy hf . One photon is absorbed by one electron.
2. Part of this energy (work function ϕ_0) frees the electron; the rest becomes its maximum KE: $hf = \phi_0 + K_{\max}$, or $K_{\max} = h(f - f_0) = eV_0$.
3. **Threshold frequency:** $K_{\max} \geq 0$ needs $f \geq f_0 = \phi_0/h$. Below f_0 , no emission.
4. **KE vs frequency:** $K_{\max}$ increases linearly with f ; intensity only changes the number of photons, not energy per photon.
5. **Current vs intensity:** more photons $\Rightarrow$ more electrons $\Rightarrow$ more current.
6. **No time lag:** one photon gives all its energy at once to one electron.
7. $V_0 = (h/e)f - \phi_0/e \Rightarrow V_0$ - f graph is a straight line of slope h/e (Millikan verified this).

★ The photoelectric effect proves the particle nature of light.

L2 State de Broglie's hypothesis. Derive the de Broglie wavelength of an electron accelerated through a potential V .

Answer:

1. **Hypothesis:** moving material particles show wave nature; wavelength $\lambda = h/p = h/mv$.

2. An electron (charge e , mass m) accelerated from rest through V gains $KE = eV = p^2/2m$.
3. $p = \sqrt{(2meV)} \Rightarrow \lambda = h/\sqrt{(2meV)}$.
4. Substituting h , m , e : $\lambda = 1.227/\sqrt{V} \text{ nm}$. For $V = 100 \text{ V}$, $\lambda \approx 0.123 \text{ nm}$ (like X-rays).
5. Confirmed by the Davisson–Germer experiment: electrons diffracted by a nickel crystal (54 V, peak at 50°) gave $\lambda = 0.165 \text{ nm}$, matching theory (0.167 nm).
6. For large objects (e.g. a 1 kg ball), λ is far too small to detect.

★ **Matter waves are important only for tiny particles like electrons.**

✓ Multiple choice questions (MCQs)

1. Energy of a photon is

- (a) h/f (b) hf
(c) $h\lambda$ (d) f/h

2. Photoelectric current depends on

- (a) frequency (b) intensity
(c) work function only (d) wavelength only

3. Stopping potential depends on

- (a) intensity (b) frequency
(c) area of plate (d) time

4. Slope of V_0 - f graph equals

- (a) h (b) h/e
(c) e/h (d) ϕ_0

5. de Broglie wavelength is

- (a) h/p (b) p/h
(c) hp (d) h/m

6. Electrons accelerated through 100 V have λ about

- (a) 1.23 nm (b) 0.123 nm
(c) 12.3 nm (d) 123 nm

7. Wave nature of electrons was confirmed by

- (a) Hertz (b) Einstein
(c) Davisson and Germer (d) Bohr

8. Rest mass of a photon is

- (a) $9.1 \times 10^{-31} \text{ kg}$ (b) zero
(c) infinite (d) $1.67 \times 10^{-27} \text{ kg}$

Answer key: 1-(b) $E = hf$. | 2-(b) Number of photons. | 3-(b) $eV_0 = hf - \phi_0$. | 4-(b) $V_0 = (h/e)f - \phi_0/e$. | 5-(a) $\lambda = h/mv$. | 6-(b) $1.227/\sqrt{V} \text{ nm}$. | 7-(c) Electron diffraction. | 8-(b) Always moves at c .

 In simple words

- **Rutherford's α -scattering:** most α -particles went straight, a few bounced back $\Rightarrow$ atom is mostly empty with a tiny, heavy, positive **nucleus**.
- Rutherford's model failed to explain atomic stability and line spectra.
- **Bohr's postulates:** (1) electrons move in fixed orbits without radiating, (2) angular momentum $mvr = nh/2\pi$, (3) a photon is emitted/absorbed when an electron jumps between orbits.
- Hydrogen **spectral series:** Lyman (to $n=1$, UV), Balmer (to $n=2$, visible), Paschen (to $n=3$, IR).

 Remember in one line

- | | |
|--|---|
| 1 Atom is mostly empty; mass and + charge sit in a tiny nucleus. | 2 Bohr: electrons move in fixed orbits without radiating. |
| 3 Angular momentum = $nh/2\pi$. | 4 $E_n = -13.6/n^2$ eV for hydrogen. |
| 5 Photon emitted when electron jumps down:
$hf = E_i - E_f$. | 6 Balmer lines are visible; Lyman UV; Paschen IR. |

 Theory in detail**Rutherford's nuclear model**

From the scattering experiment Rutherford concluded: (1) the positive charge and almost all mass of the atom is concentrated in a tiny **nucleus** ($\sim 10^{-15}$ m); (2) electrons revolve around it like planets around the Sun; (3) the atom ($\sim 10^{-10}$ m) is mostly empty space. The attraction between nucleus and electron provides the needed centripetal force.

Line spectra

When hydrogen gas is excited by electric discharge, it emits light of only certain definite wavelengths — a **line spectrum**, not a continuous rainbow. Each element has its own fingerprint spectrum, which is used to identify elements in stars. Bohr's model explained these lines as jumps between fixed energy levels.

Stationary orbits

Bohr said electrons can revolve only in certain allowed orbits (stationary states) where angular momentum is a whole-number multiple of $h/2\pi$. In these orbits they do **not** radiate energy, even though they are accelerating. Energy is emitted or absorbed only during a jump: $hf = E_i - E_f$.

Why the atom does not collapse

According to classical physics, an electron moving in a circle is accelerating and should continuously radiate energy, spiral inward and fall into the nucleus in about 10^{-8} s. Since atoms are stable, classical physics fails at atomic scale. Bohr solved this by allowing only certain stationary orbits where the electron does not radiate.

Ionisation and excitation

When an atom absorbs energy, its electron can jump to a higher orbit (**excitation**); it returns within about 10^{-8} s, emitting light. If the energy is enough to remove the electron completely ($n = \infty$), the atom is **ionised**. For hydrogen, ionisation energy = 13.6 eV and ionisation potential = 13.6 V.

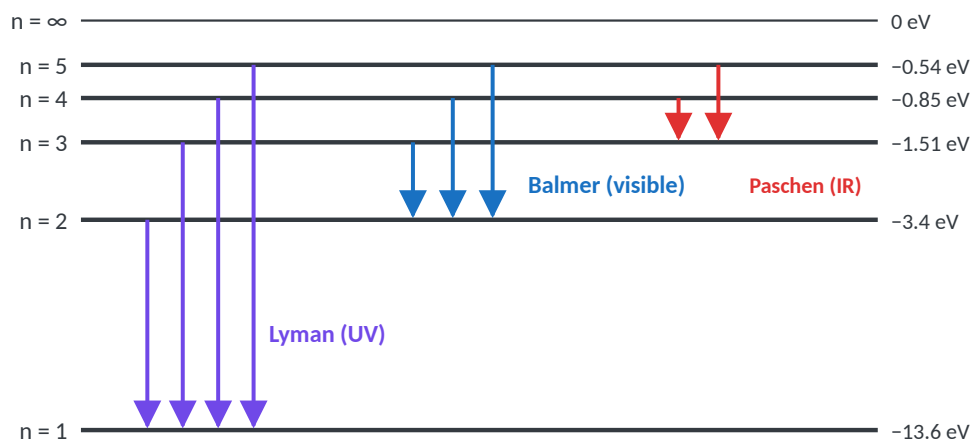


 Fig. 12.1: Energy levels of hydrogen and spectral series

More theory - explained

- **Thomson's model:** positive charge spread like pudding with electrons embedded — failed to explain large-angle α -scattering.
- **Geiger-Marsden experiment:** α -particles on a thin gold foil. Most pass straight; about 1 in 8000 bounce back more than 90° .
- **Distance of closest approach:** all KE $\rightarrow$ PE, $r_0 = k(2e)(Ze)/K$. Gives an upper limit to nuclear size ($\sim 10^{-14}$ m). **Impact parameter:** small $\Rightarrow$ large scattering angle.
- **Failure of Rutherford's model:** a revolving electron is accelerating, should radiate, spiral into the nucleus and give a continuous spectrum.
- **Bohr's derivations:** $mv^2/r = kZe^2/r^2$ and $mvr = nh/2\pi \Rightarrow r_n \propto n^2/Z$, $v_n \propto Z/n$, $E_n = -13.6Z^2/n^2$ eV. Also KE = -E, PE = 2E.
- **Energy levels:** ground state $n = 1$ (-13.6 eV). Ionisation energy = 13.6 eV; 1st and 2nd excitation energies = 10.2 eV and 12.09 eV.
- **Spectral series:** Lyman (to $n = 1$, UV); Balmer (to $n = 2$, visible — H α 656 nm red); Paschen ($n = 3$, IR); Brackett ($n = 4$, IR); Pfund ($n = 5$, IR). Lines possible from level $n = n(n-1)/2$.
- **de Broglie's explanation:** an electron orbit holds a whole number of waves, $2\pi r = n\lambda \Rightarrow mvr = nh/2\pi$ (Bohr's condition).
- **Limitations of Bohr model:** works only for one-electron atoms (H, He $^+$, Li $^{2+}$), cannot explain line intensities or fine structure.

Key formulas

$$r_n = 0.529 n^2 \text{ \AA}$$

$$v_n = 2.18 \times 10^6/n \text{ m/s}$$

$$E_n = -13.6/n^2 \text{ eV}$$

$$hf = E_i - E_f$$

$$1/\lambda = R(1/n_f^2 - 1/n_i^2), R = 1.097 \times 10^7 \text{ m}^{-1}$$

Quick 1-mark questions

Why did most α -particles go straight?	Atom is mostly empty space
Which series lies in the visible region?	Balmer
Ratio of radii of 1st and 2nd Bohr orbits?	1 : 4

Solved problems (9)

Q1 Find the radius of the 2nd Bohr orbit of hydrogen.

$$1. r_n = 0.529 n^2 \text{ \AA} = 0.529 \times 4$$

✓ Answer: $r_2 = 2.12 \text{ \AA}$

Q2 An electron jumps from $n = 2$ to $n = 1$ in hydrogen. Find the energy and wavelength of the photon.

$$1. E_1 = -13.6 \text{ eV}, E_2 = -13.6/4 = -3.4 \text{ eV}$$

$$2. \Delta E = -3.4 - (-13.6) = 10.2 \text{ eV}$$

$$3. \lambda = 1240/10.2 \text{ nm}$$

✓ Answer: 10.2 eV, $\lambda \approx 122 \text{ nm}$ (Lyman, UV)

Q3 How much energy is needed to remove an electron from $n = 3$?

$$1. E_3 = -13.6/9 = -1.51 \text{ eV}$$

$$2. \text{Energy needed} = 0 - (-1.51)$$

✓ Answer: 1.51 eV

Q4 Find the closest approach of a 7.7 MeV α -particle to a gold nucleus ($Z = 79$).

$$1. r_0 = k(2e)(Ze)/K = 9 \times 10^9 \times 2 \times 79 \times (1.6 \times 10^{-19})^2 / (7.7 \times 1.6 \times 10^{-13})$$

✓ Answer: $\approx 3 \times 10^{-14} \text{ m}$ (30 fm)

Q5 How many spectral lines are possible when electrons fall from $n = 4$?

$$1. N = n(n-1)/2 = 4 \times 3/2$$

✓ Answer: 6

Q6 Find the wavelength of $H\alpha$ ($n = 3 \rightarrow 2$). ($R = 1.097 \times 10^7 \text{ m}^{-1}$)

$$1. 1/\lambda = R(1/4 - 1/9) = 1.097 \times 10^7 \times 5/36 \approx 1.52 \times 10^6$$

✓ Answer: $\lambda \approx 656 \text{ nm}$ (red)

Q7 Find KE and PE of the electron in the ground state of hydrogen.

1. $E = -13.6 \text{ eV}$
2. $\text{KE} = -E, \text{PE} = 2E$

✓ Answer: $\text{KE} = 13.6 \text{ eV}, \text{PE} = -27.2 \text{ eV}$

Q8 Find the shortest wavelength of the Lyman series.

1. $n = \infty \rightarrow 1: 1/\lambda = R$
2. $\lambda = 1/1.097 \times 10^7$

✓ Answer: $\approx 91.2 \text{ nm}$

Q9 Find the ground-state energy of He^+ ($Z = 2$).

1. $E = -13.6 Z^2 = -13.6 \times 4$

✓ Answer: -54.4 eV

Long answer questions (5 marks)

L1 Using Bohr's postulates, derive the expressions for radius, velocity and energy of the electron in the n -th orbit of hydrogen atom.

Answer:

1. Electron (mass m , charge e) revolves round nucleus (charge Ze) in orbit of radius r with speed v .
2. Centripetal force = electrostatic force: $mv^2/r = kZe^2/r^2 \dots (1)$
3. Quantisation: $mvr = nh/2\pi \dots (2)$
4. From (1) and (2): $r_n = n^2 h^2 \epsilon_0 / (\pi m Z e^2) = 0.529 n^2 / Z \text{ \AA}$; $v_n = Ze^2 / (2 \epsilon_0 n h) = 2.18 \times 10^6 Z/n \text{ m/s}$.
5. Energy: $\text{KE} = \frac{1}{2}mv^2 = kZe^2/2r$; $\text{PE} = -kZe^2/r \Rightarrow E = -kZe^2/2r$.
6. Substituting r_n : $E_n = -mZ^2 e^4 / (8 \epsilon_0^2 n^2 h^2) = -13.6 Z^2 / n^2 \text{ eV}$. Negative sign means the electron is bound.

★ $r \propto n^2, v \propto 1/n, E \propto -1/n^2$.

L2 Explain the hydrogen spectrum on the basis of Bohr's theory.

Answer:

1. When an electron jumps from a higher level n_i to a lower level n_f , a photon is emitted: $hf = E_i - E_f = 13.6(1/n_f^2 - 1/n_i^2) \text{ eV}$.
2. Using $f = c/\lambda$: $1/\lambda = R(1/n_f^2 - 1/n_i^2)$, $R = 1.097 \times 10^7 \text{ m}^{-1}$ (Rydberg constant).
3. **Lyman series**: $n_f = 1, n_i = 2, 3, \dots$ — ultraviolet.
4. **Balmer series**: $n_f = 2$ — visible ($H\alpha$ red 656 nm, $H\beta$ blue-green 486 nm, $H\gamma$, $H\delta$ violet).
5. **Paschen** ($n_f = 3$), **Brackett** (4), **Pfund** (5) — infrared.

6. Since only certain energy differences are possible, only certain wavelengths appear — a line spectrum.

★ Bohr's model beautifully explained why hydrogen gives a line spectrum.

✓ Multiple choice questions (MCQs)

1. α -scattering experiment showed that the atom has

- (a) uniform charge (b) a small massive nucleus
(c) no electrons (d) neutrons

2. Ground-state energy of hydrogen is

- (a) 13.6 eV (b) -13.6 eV
(c) -3.4 eV (d) 0

3. Radius of Bohr orbit varies as

- (a) n (b) n^2
(c) $1/n$ (d) $1/n^2$

4. Balmer series lies in

- (a) UV (b) visible
(c) infrared (d) X-ray

5. Angular momentum in the n -th orbit is

- (a) nh (b) $nh/2\pi$
(c) $h/2\pi n$ (d) $2\pi nh$

6. Ionisation energy of hydrogen is

- (a) 10.2 eV (b) 3.4 eV
(c) 13.6 eV (d) 1.51 eV

7. Number of spectral lines from $n = 3$ to ground is

- (a) 1 (b) 2
(c) 3 (d) 6

8. Velocity of electron in n -th orbit varies as

- (a) n (b) $1/n$
(c) n^2 (d) $1/n^2$

Answer key: 1-(b) Few large deflections. | 2-(b) $n = 1$. | 3-(b) $r = 0.529 n^2 \text{ \AA}$. | 4-(b) Transitions to $n = 2$. | 5-(b) Bohr's postulate. | 6-(c) From $n = 1$ to ∞ . | 7-(c) $n(n-1)/2$. | 8-(b) $v \propto Z/n$.

13 Nuclei

Class XII · Unit VIII

In simple words

- A nucleus has **protons (Z)** and **neutrons (N)**. Mass number $A = Z + N$. Radius $R = R_0 A^{1/3}$ (so nuclear density is the same for all nuclei).
- **Nuclear force**: very strong, short range ($\sim$ fm), attractive, charge-independent.
- **Mass defect**: nucleus weighs less than its separate nucleons. This missing mass becomes **binding energy** ($E = mc^2$).
- BE per nucleon is highest near $A \approx 56$ (iron) – most stable. Heavy nuclei split (**fission**) and light nuclei join (**fusion**) to release energy.
- Fission: nuclear reactors, atom bomb. Fusion: energy of the Sun and stars.

Remember in one line

- | | |
|--|---|
| 1 Nucleus = protons + neutrons (nucleons). | 2 Radius $R = R_0 A^{1/3}$; density same for all nuclei. |
| 3 Nuclear force: very strong, very short range. | 4 Missing mass (mass defect) becomes binding energy ($E = mc^2$). |
| 5 Fe-56 is most stable (highest BE per nucleon). | 6 Heavy nuclei split (fission); light nuclei join (fusion). |

Theory in detail

Composition of nucleus

A nucleus contains protons and neutrons, together called **nucleons**. Neutron was discovered by Chadwick in 1932. Z = number of protons (atomic number), N = number of neutrons, $A = Z + N$ (mass number). Protons repel each other strongly, so an attractive **nuclear force** much stronger than electric force is needed to hold them together.

Mass-energy relation

Einstein showed mass and energy are interchangeable: $E = mc^2$. Even a tiny mass gives huge energy because c^2 is enormous ($9 \times 10^{16} \text{ m}^2/\text{s}^2$). In nuclear reactions, the total mass of products is slightly less than the reactants; this missing mass appears as energy (Q-value).

Binding energy

Binding energy is the energy required to break a nucleus completely into its separate protons and neutrons (or the energy released when they come together). Higher binding energy per nucleon means a more stable nucleus. Nuclear energy is released whenever nucleons move into a state of higher BE per nucleon.

Size of nucleus

Scattering experiments show that nuclear radius $R = R_0 A^{1/3}$ with $R_0 \approx 1.2 \text{ fm}$. The nucleus is about 10^4 to 10^5 times smaller than the atom. Volume $\propto A$, so all nuclei have almost the same

density ($\sim 2.3 \times 10^{17} \text{ kg/m}^3$) — a matchbox of nuclear matter would weigh billions of tonnes.

Energy from the Sun and stars

In the Sun's core, the temperature is about $1.5 \times 10^7 \text{ K}$. Hydrogen nuclei fuse to form helium by the proton-proton cycle, releasing 26.7 MeV per helium nucleus. The Sun converts about 4 million tonnes of mass into energy every second, and has enough hydrogen to shine for billions of years.

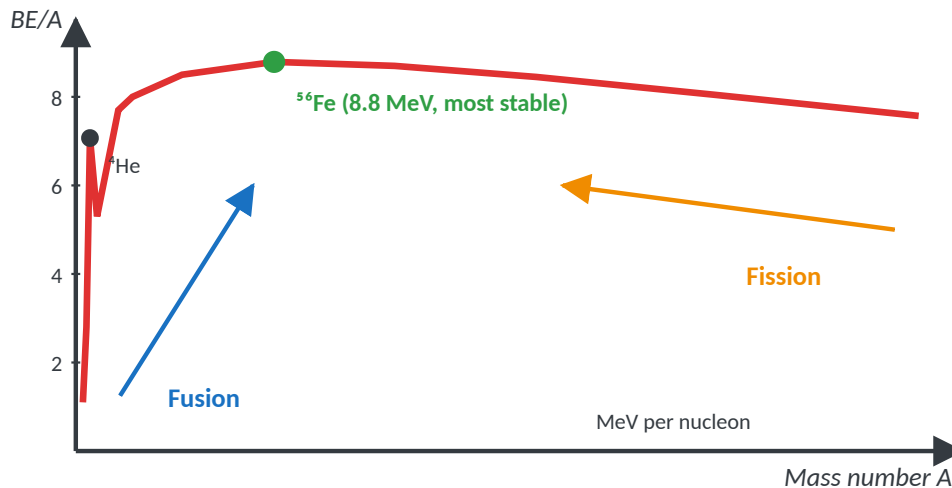


Fig. 13.1: Binding energy per nucleon vs mass number

More theory - explained

- **Notation** ${}^A_Z\text{X}$. **Isotopes** — same Z (${}^{12}\text{C}$, ${}^{14}\text{C}$); **isobars** — same A (${}^3\text{H}$, ${}^3\text{He}$); **isotones** — same N .
- **Atomic mass unit**: $1 \text{ u} = 1/12$ of mass of a ${}^{12}\text{C}$ atom $= 1.66 \times 10^{-27} \text{ kg} \approx 931.5 \text{ MeV}$.
- **Nuclear density** $\approx 2.3 \times 10^{17} \text{ kg/m}^3$, same for all nuclei because $R^3 \propto A$.
- **Nuclear force**: strongest force, short range (2–3 fm), charge-independent (p–p, n–n, p–n same), saturates (each nucleon pulls only its neighbours), attractive but repulsive below $\sim 0.8 \text{ fm}$.
- **BE/A curve**: rises sharply for light nuclei, flat peak $\sim 8.75 \text{ MeV}$ near $A = 56$ (Fe), falls to $\sim 7.6 \text{ MeV}$ for U-238. Heavy nuclei gain stability by **splitting**, light nuclei by **joining**.
- **Fission**: ${}^{235}\text{U} + n \rightarrow {}^{141}\text{Ba} + {}^{92}\text{Kr} + 3n + \sim 200 \text{ MeV}$. Extra neutrons cause a **chain reaction**.
- **Nuclear reactor**: fuel (enriched U), moderator (heavy water/graphite — slows neutrons), control rods (cadmium/boron — absorb neutrons), coolant, shielding. Uncontrolled chain reaction = atom bomb.
- **Fusion**: light nuclei combine at $\sim 10^7 \text{ K}$ (thermonuclear). In the Sun: $4 {}^1\text{H} \rightarrow {}^4\text{He} + 2e^+ + 2\nu + 26.7 \text{ MeV}$. Uncontrolled fusion = hydrogen bomb.

Key formulas

$$R = R_0 A^{1/3}, R_0 = 1.2 \text{ fm}$$

$$\Delta m = [Zm_p + (A-Z)m_n] - M$$

$$BE = \Delta m c^2; 1 \text{ u} = 931.5 \text{ MeV}$$

$$E = mc^2$$

🚀 Quick 1-mark questions

Most stable nucleus?

^{56}Fe

Why are neutrons good for causing fission?

No charge, so no repulsion

Role of moderator?

Slows down fast neutrons

📝 Solved problems (8)

Q1 Find the radius of an aluminium nucleus ($A = 27$).

$$1. R = 1.2 \times (27)^{1/3} \text{ fm} = 1.2 \times 3$$

✓ Answer: $R = 3.6 \text{ fm}$

Q2 Find the binding energy per nucleon of ^4He . ($m_p = 1.00728 \text{ u}$, $m_n = 1.00866 \text{ u}$, nucleus = 4.00151 u)

$$1. \text{ Mass of nucleons} = 2(1.00728) + 2(1.00866) = 4.03188 \text{ u}$$

$$2. \Delta m = 4.03188 - 4.00151 = 0.03037 \text{ u}$$

$$3. BE = 0.03037 \times 931.5 \approx 28.3 \text{ MeV}; \text{ per nucleon} = 28.3/4$$

✓ Answer: $\approx 7.07 \text{ MeV per nucleon}$

Q3 How much energy is obtained if 1 g of matter is fully converted to energy?

$$1. E = mc^2 = 10^{-3} \times (3 \times 10^8)^2$$

✓ Answer: $E = 9 \times 10^{13} \text{ J}$

Q4 Find the ratio of radii of nuclei with $A = 27$ and $A = 125$.

$$1. R \propto A^{1/3} \Rightarrow (27/125)^{1/3}$$

✓ Answer: $3 : 5$

Q5 Estimate nuclear density. ($R_0 = 1.2 \text{ fm}$, $m \approx 1.66 \times 10^{-27} \text{ kg per nucleon}$)

$$1. \rho = m / (4/3 \pi R_0^3) = 1.66 \times 10^{-27} / (4.19 \times 1.73 \times 10^{-45})$$

✓ Answer: $\approx 2.3 \times 10^{17} \text{ kg/m}^3$

Q6 Find the binding energy of the deuteron ($m_p = 1.00728 \text{ u}$, $m_n = 1.00866 \text{ u}$, $m_d = 2.01355 \text{ u}$).

$$1. \Delta m = 1.00728 + 1.00866 - 2.01355 = 0.00239 \text{ u}$$

$$2. BE = 0.00239 \times 931.5$$

✓ Answer: $\approx 2.23 \text{ MeV (1.11 MeV per nucleon)}$

Q7 Find energy released when 1 kg of ^{235}U fissions fully (200 MeV per fission).

1. $N = (1000/235) \times 6.02 \times 10^{23} \approx 2.56 \times 10^{24}$

2. $E = 2.56 \times 10^{24} \times 200 \times 1.6 \times 10^{-13} \text{ J}$

✓ Answer: $\approx 8.2 \times 10^{13} \text{ J}$

Q8 Find Q for $^2\text{H} + ^2\text{H} \rightarrow ^3\text{He} + \text{n}$. (2.014102, 3.016029, 1.008665 u)

1. $\Delta m = 2 \times 2.014102 - (3.016029 + 1.008665) = 0.00351 \text{ u}$

2. $Q = 0.00351 \times 931.5$

✓ Answer: $\approx 3.27 \text{ MeV}$

Long answer questions (5 marks)

L1 What is binding energy per nucleon? Draw and explain its variation with mass number.

Answer:

1. **Mass defect:** $\Delta m = [Zm_p + (A - Z)m_n] - M_{\text{nucleus}}$. **BE** = $\Delta m c^2$; **BE per nucleon** = BE/A .
2. Graph of BE/A vs A : rises steeply for light nuclei (with peaks at He-4, C-12, O-16), reaches a broad maximum of about **8.75 MeV near $A = 56$** (Fe), then decreases slowly to about 7.6 MeV for U-238.
3. **Middle region ($30 < A < 170$):** BE/A almost constant because nuclear force is short-range and saturated — each nucleon attracts only near neighbours.
4. **Heavy nuclei:** BE/A lower due to increased Coulomb repulsion $\Rightarrow$ splitting into two medium nuclei releases energy (**fission**).
5. **Light nuclei:** BE/A low $\Rightarrow$ combining them into a heavier nucleus releases energy (**fusion**).

★ The BE curve explains why both fission and fusion release energy.

L2 Distinguish between nuclear fission and fusion. Explain the chain reaction.

Answer:

1. **Fission:** a heavy nucleus splits into two medium nuclei when hit by a slow neutron, e.g. $^{235}\text{U} + \text{n} \rightarrow ^{141}\text{Ba} + ^{92}\text{Kr} + 3\text{n} + \sim 200 \text{ MeV}$.
2. **Fusion:** two light nuclei combine into a heavier nucleus, e.g. $^2\text{H} + ^3\text{H} \rightarrow ^4\text{He} + \text{n} + 17.6 \text{ MeV}$.
3. **Differences:** fission occurs at normal temperature, fusion needs $\sim 10^7 \text{ K}$; fission leaves radioactive waste, fusion products are mostly harmless; energy per nucleon is larger in fusion; fission is used in reactors, fusion powers the Sun.
4. **Chain reaction:** each fission gives 2–3 neutrons, which cause more fissions; the number grows rapidly.
5. **Controlled** (reactor): moderators slow neutrons, control rods (Cd, B) absorb extra neutrons so exactly one neutron per fission continues. **Uncontrolled:** atom bomb.
6. A minimum amount of fuel, the **critical mass**, is needed to sustain a chain reaction.

★ Fission is used in nuclear power plants; fusion is the energy source of stars.

✓ Multiple choice questions (MCQs)

1. Nuclear radius is proportional to

- (a) A
- (b) A^2
- (c) $A^{1/3}$
- (d) $A^{2/3}$

2. 1 u is equivalent to

- (a) 931.5 MeV
- (b) 1 MeV
- (c) 13.6 eV
- (d) 200 MeV

3. Nuclear forces are

- (a) long range
- (b) short range
- (c) only repulsive
- (d) electric

4. Most stable nucleus is

- (a) U-235
- (b) He-4
- (c) Fe-56
- (d) H-1

5. Energy of the Sun comes from

- (a) fission
- (b) fusion
- (c) burning
- (d) radioactivity

6. Energy released per fission of U-235 is about

- (a) 2 MeV
- (b) 20 MeV
- (c) 200 MeV
- (d) 2000 MeV

7. Control rods in a reactor are made of

- (a) graphite
- (b) cadmium or boron
- (c) heavy water
- (d) uranium

8. Isotopes have the same

- (a) mass number
- (b) number of neutrons
- (c) atomic number
- (d) mass

Answer key: 1-(c) $R = R_0 A^{1/3}$. | 2-(a) $E = mc^2$. | 3-(b) $\sim 2-3$ fm. | 4-(c) Max BE/A. | 5-(b) $H \rightarrow He$. | 6-(c) ≈ 200 MeV. | 7-(b) Absorb neutrons. | 8-(c) Same Z.

14 Semiconductor Electronics

Class XII · Unit IX

In simple words

- **Energy bands:** Conductors – bands overlap. Insulators – large gap (> 3 eV). Semiconductors – small gap (Si 1.1 eV, Ge 0.7 eV).
- **Intrinsic** semiconductor is pure: $n_e = n_h = n_i$.
- **n-type:** add pentavalent impurity (P, As) $\Rightarrow$ electrons are majority carriers. **p-type:** add trivalent impurity (B, Al) $\Rightarrow$ holes are majority.
- **p-n junction** forms a **depletion layer** with a barrier potential.
- **Forward bias** (p to +): barrier falls, large current. **Reverse bias:** very small current until breakdown.
- A diode allows current one way, so it is used as a **rectifier** (AC $\rightarrow$ DC).

Remember in one line

- | | |
|---|---|
| 1 Conductors: no gap; insulators: big gap; semiconductors: small gap. | 2 Pure semiconductor = intrinsic; doped = extrinsic. |
| 3 n-type: extra electrons; p-type: extra holes. | 4 p-n junction has a depletion layer and barrier potential. |
| 5 Forward bias: big current; reverse bias: tiny current. | 6 Diodes change AC to DC (rectifiers). |

Theory in detail

Energy bands in simple words

In a single atom, electrons occupy sharp energy levels. In a solid, many atoms come close and these levels spread into **bands**. The filled band is the **valence band**, the next empty one is the **conduction band**, and the gap between them is the **forbidden energy gap** E_g . Electrons in the conduction band can move and carry current.

Holes

When an electron leaves a covalent bond in a semiconductor, it leaves behind a vacancy called a **hole**. A neighbouring electron can jump into the hole, so the hole appears to move in the opposite direction. Holes behave like positive charges of size e . In an intrinsic semiconductor number of holes equals number of free electrons.

Why semiconductors matter

By adding tiny amounts of impurity, the conductivity of silicon can be increased thousands of times and controlled precisely. This allows us to make diodes, transistors, LEDs, solar cells and integrated circuits — the basis of all modern electronics, from mobile phones to computers.

Intrinsic vs extrinsic semiconductors

A pure semiconductor (Si, Ge) is **intrinsic**; it has very few carriers at room temperature, so conductivity is low. Adding a tiny amount of impurity (**doping**) makes it **extrinsic**. Pentavalent impurity (P, As, Sb) gives extra free electrons (n-type); trivalent impurity (B, Al, In) gives extra holes (p-type). Doping increases conductivity enormously.

Diode as a rectifier and filter

A diode allows current in only one direction, so it can turn AC into pulsating DC. A half-wave rectifier uses one diode; a full-wave rectifier uses two diodes (or four in a bridge). To make the output smooth, a capacitor is connected across the load: it charges at the peaks and discharges slowly between them, reducing the ripple. Mobile phone chargers use this idea.

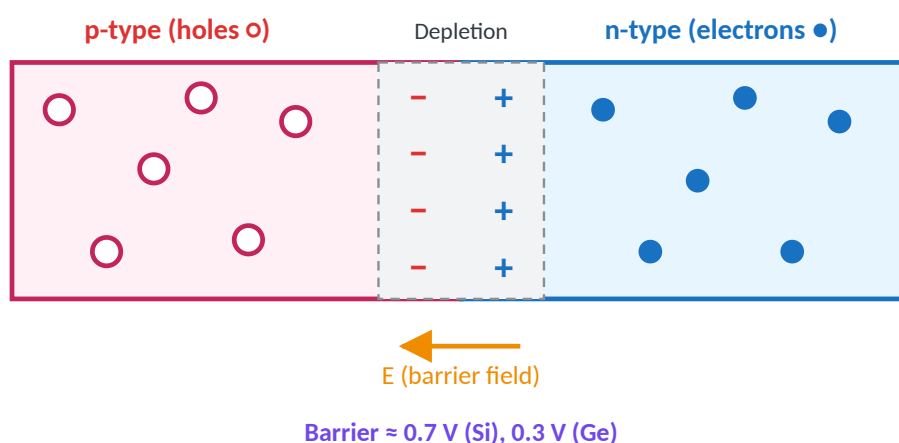


Fig. 14.1: p-n junction and its depletion layer

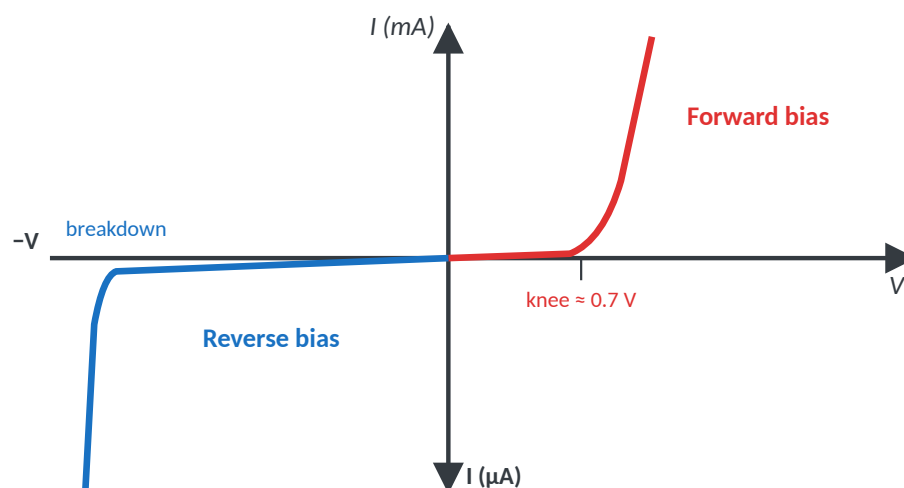


Fig. 14.2: V-I characteristics of a p-n junction diode

More theory - explained

- **Band gaps:** metals 0 (bands overlap); Ge ≈ 0.7 eV, Si ≈ 1.1 eV; diamond (insulator) ≈ 5.4 eV.
- **Intrinsic semiconductor:** at 0 K it is an insulator. At room temperature some electrons jump to the conduction band leaving **holes** (act as + charge). Current = electron current + hole current.
- **Doping:** about 1 impurity atom per 10^6 – 10^8 atoms. Donor level lies just below conduction band (n-type); acceptor level just above valence band (p-type). Doped crystal is still **electrically**

neutral.

- **Formation of p-n junction:** electrons diffuse to p-side, holes to n-side, leaving fixed ions — the **depletion layer** ($\sim 1 \mu\text{m}$). Its field stops further diffusion; barrier $\approx 0.7 \text{ V}$ (Si), 0.3 V (Ge). Minority carriers drift across.
- **Forward bias:** depletion layer narrows; current rises sharply after the knee voltage (mA). **Reverse bias:** layer widens; tiny μA current due to minority carriers until breakdown.
- **Dynamic resistance** $r_d = \Delta V / \Delta I$ (from the V-I graph).
- **Half-wave rectifier:** one diode, conducts only in positive half; output frequency f .
- **Full-wave rectifier** (centre-tap): two diodes conduct in turn, output in both halves; output frequency $2f$. A capacitor filter smooths the pulsating DC.
- **Zener diode** (practical): heavily doped, works in reverse breakdown with nearly constant voltage — used as a voltage regulator.

Key formulas

$$n_e n_h = n_i^2$$

$$\text{Half-wave output frequency} = f$$

$$\text{Full-wave output frequency} = 2f$$

$$\text{Si diode knee voltage} \approx 0.7 \text{ V}$$

Quick 1-mark questions

Majority carriers in p-type?

Holes

Is p-type semiconductor positively charged?

No, it is neutral

Effect of forward bias on depletion width?

It decreases

Solved problems (8)

Q1 An AC of 50 Hz is rectified. Find the output ripple frequency for half-wave and full-wave rectifiers.

1. Half-wave passes one half-cycle per cycle $\Rightarrow f$
2. Full-wave uses both halves $\Rightarrow 2f$

✓ Answer: Half-wave: 50 Hz, Full-wave: 100 Hz

Q2 Pure Si has $n_i = 1.5 \times 10^{16} \text{ m}^{-3}$. It is doped with 10^{22} m^{-3} arsenic atoms. Find n_e and n_h .

1. As is pentavalent $\Rightarrow n_e \approx 10^{22} \text{ m}^{-3}$
2. $n_h = n_i^2 / n_e = 2.25 \times 10^{32} / 10^{22}$

✓ Answer: $n_e = 10^{22}$, $n_h = 2.25 \times 10^{10} \text{ m}^{-3}$ (n-type)

Q3 A Si diode in forward bias is in series with $1\text{ k}\Omega$ and a 5 V battery. Find the current.

1. Voltage across $R = 5 - 0.7 = 4.3\text{ V}$
2. $I = 4.3/1000$

✓ Answer: $I = 4.3\text{ mA}$

Q4 A diode's current rises from 10 mA to 30 mA when V rises from 0.7 V to 0.8 V . Find r_d .

1. $r_d = \Delta V / \Delta I = 0.1/0.02$

✓ Answer: $5\ \Omega$

Q5 Si ($5 \times 10^{28}\text{ atoms/m}^3$) is doped with 1 ppm arsenic. Find n_e and n_h . ($n_i = 1.5 \times 10^{16}\text{ m}^{-3}$)

1. $N_D = 5 \times 10^{28} \times 10^{-6} = 5 \times 10^{22} \Rightarrow n_e \approx 5 \times 10^{22}$
2. $n_h = n_i^2/n_e = 2.25 \times 10^{32}/5 \times 10^{22}$

✓ Answer: $n_e = 5 \times 10^{22}$, $n_h = 4.5 \times 10^9\text{ m}^{-3}$

Q6 What is the longest wavelength of light that can create electron-hole pairs in Si ($E_g = 1.1\text{ eV}$)?

1. $\lambda = 1240/E_g\text{ nm} = 1240/1.1$

✓ Answer: $\approx 1127\text{ nm}$

Q7 A half-wave rectifier gets 10 V peak AC. Find peak output with (a) an ideal diode (b) a Si diode.

1. (a) no drop $\Rightarrow 10\text{ V}$
2. (b) $10 - 0.7$

✓ Answer: 10 V ; 9.3 V

Q8 A 6 V Zener is used with 10 V input and a $200\ \Omega$ series resistor. Find current through the resistor.

1. V across $R = 10 - 6 = 4\text{ V}$
2. $I = 4/200$

✓ Answer: 20 mA



Long answer questions (5 marks)

L1 Explain the formation of depletion region and barrier potential in a p-n junction. Draw and explain the V-I characteristics of a junction diode.

Answer:

1. When p-type and n-type regions are joined, holes diffuse from p to n and electrons from n to p (because of concentration difference).

2. They leave behind immobile negative ions on the p-side and positive ions on the n-side near the junction. This thin layer with no free carriers is the **depletion region**.
3. The ions create an electric field from n to p, which opposes further diffusion. The potential difference across it is the **barrier potential** (~ 0.7 V for Si, ~ 0.3 V for Ge). Equilibrium is reached when diffusion current = drift current.
4. **Forward bias** (p to +, n to -): barrier reduces, depletion layer narrows. Current is very small until the **knee (threshold) voltage**, then rises sharply (mA).
5. **Reverse bias** (p to -, n to +): barrier increases, layer widens. Only a tiny reverse saturation current (μA) flows due to minority carriers, nearly independent of voltage, until **breakdown** where current rises suddenly.
6. The curve is non-linear, so a diode does not obey Ohm's law; it conducts easily in one direction only.

★ A diode is a one-way valve for electric current.

L2 Explain with circuit description the working of a half-wave and a full-wave rectifier.

Answer:

1. **Rectifier:** circuit that changes AC into DC, using the one-way property of diodes.
2. **Half-wave:** AC from a transformer secondary is applied to a diode in series with load R_L . In the positive half cycle the diode is forward-biased and current flows through R_L ; in the negative half it is reverse-biased and no current flows. Output: pulses in alternate halves only; output frequency = input frequency (50 Hz); efficiency $\approx 40.6\%$.
3. **Full-wave (centre-tap):** a centre-tapped transformer and two diodes D_1, D_2 . In the positive half D_1 conducts, in the negative half D_2 conducts; current through R_L is in the same direction both times.
4. Output: pulses in both halves; output frequency = $2 \times$ input (100 Hz); efficiency $\approx 81.2\%$.
5. The output is pulsating DC; a **capacitor filter** across R_L charges at peaks and discharges slowly between them, giving smoother DC.

★ Full-wave rectification uses both halves of AC and is more efficient.

✓ Multiple choice questions (MCQs)

1. Majority carriers in n-type semiconductor are

- | | |
|-------------|---------------|
| (a) holes | (b) electrons |
| (c) protons | (d) ions |

2. To make p-type Si, we add

- | | |
|----------------|--------------|
| (a) phosphorus | (b) arsenic |
| (c) boron | (d) antimony |

3. Band gap of silicon is about

- | | |
|------------|-------------|
| (a) 0.1 eV | (b) 1.1 eV |
| (c) 5.4 eV | (d) 13.6 eV |

4. In forward bias, depletion layer

- | | |
|---------------|--------------------------|
| (a) widens | (b) narrows |
| (c) unchanged | (d) vanishes permanently |

5. Output frequency of a full-wave rectifier (input 50 Hz) is

- (a) 25 Hz
- (b) 50 Hz
- (c) 100 Hz
- (d) 200 Hz

6. Resistance of a semiconductor on heating

- (a) increases
- (b) decreases
- (c) stays same
- (d) becomes infinite

7. In an intrinsic semiconductor

- (a) $n_e > n_h$
- (b) $n_e < n_h$
- (c) $n_e = n_h$
- (d) no carriers ever

8. Barrier potential of a Si junction is about

- (a) 0.3 V
- (b) 0.7 V
- (c) 1.5 V
- (d) 5 V

Answer key: 1-(b) Donor impurity. | 2-(c) Trivalent impurity. | 3-(b) Standard value. | 4-(b) Barrier reduced. | 5-(c) Both halves used. | 6-(b) More carriers. | 7-(c) Pairs created together. | 8-(b) Standard value.

Useful Constants & Exam Tips

Quick revision

Speed of light c	$3 \times 10^8 \text{ m/s}$
Gravitational constant G	$6.67 \times 10^{-11} \text{ N m}^2/\text{kg}^2$
g on Earth	9.8 m/s^2
Radius of Earth R	$6.4 \times 10^6 \text{ m}$
Electron charge e	$1.6 \times 10^{-19} \text{ C}$
Electron mass m_e	$9.1 \times 10^{-31} \text{ kg}$
Planck's constant h	$6.63 \times 10^{-34} \text{ J s}$
ϵ_0	$8.85 \times 10^{-12} \text{ C}^2/\text{N m}^2$
μ_0	$4\pi \times 10^{-7} \text{ T m/A}$
Gas constant R	8.314 J/mol K
Boltzmann k_B	$1.38 \times 10^{-23} \text{ J/K}$
Avogadro N_A	$6.02 \times 10^{23} / \text{mol}$
1 u	$1.66 \times 10^{-27} \text{ kg} = 931.5 \text{ MeV}$
1 eV	$1.6 \times 10^{-19} \text{ J}$

Exam tips

- Write the **given data** first, with units converted to SI ($\text{cm} \rightarrow \text{m}$, $\mu\text{C} \rightarrow 10^{-6} \text{ C}$).
- Write the **formula**, then substitute, then the answer **with unit**. Each step earns marks.
- Follow the **sign convention** carefully in mirror and lens sums.
- Draw a **neat labelled diagram** wherever possible (ray diagrams, circuits, graphs).
- Check your answer with **common sense**: drift velocity is tiny, escape speed $\sim 11 \text{ km/s}$, etc.
- Revise the yellow formula boxes daily – 10 minutes a day is enough.
- For derivations, remember the **starting idea** and the **final result**; the middle steps follow.

Based on the CHSE Odisha Physics syllabus 2023–24 • Reference: NCERT Physics Class XI & XII