



Chapter 3 : Current Electricity (Notes)

by - Tomar Sir

Notes

GSEB and CBSE Board Exam preparation subjective notes · Class 12 Physics · NCERT Chapter 3

Q.1 Define electric current. Write its SI unit. Is current a scalar or a vector? (2 Marks)

Electric current: The **rate of flow of charge** through any cross-section of a conductor.

If a net charge q flows across an area in time t (steady current):

$$I = \frac{q}{t}$$

If the current is not steady, the current at time t is

$$I(t) = \lim_{\Delta t \rightarrow 0} \frac{\Delta Q}{\Delta t} = \frac{dQ}{dt}$$

The net charge in the forward direction is $q = q_+ - q_-$, where q_+ is the net positive charge and q_- the net negative charge crossing in the forward direction.

SI unit: ampere (A). $1 \text{ A} = 1 \text{ C s}^{-1}$. (The ampere is defined through the magnetic effects of currents.)

Dimensions: $[A]$ — it is a base quantity.

Typical values: domestic appliances — about 1 A; lightning — tens of thousands of amperes; currents in our nerves — microamperes.

Key Examination Points for Full Marks:

- **Current is a scalar**, even though we show it with an arrow. Currents **do not obey the law of vector addition**. Also, $I = \vec{j} \cdot \Delta \vec{S}$ is a scalar product of two vectors.
- The conventional direction of current is the direction of flow of **positive charge** (opposite to electron flow).

Q.2 Explain how current flows in a conductor. Why is there no current without an electric field? (2 Marks)

In the absence of an electric field: In a metal, free electrons move randomly due to thermal motion, colliding with the fixed positive ions. After each collision, an electron moves with the same speed but in a random direction. The number of electrons moving in any direction equals the number moving in the opposite direction, so **there is no net current**.

When an electric field is applied: Consider a metallic cylinder with charges $+Q$ and $-Q$ at its ends (Fig. 3.1). An electric field is set up from $+Q$ to $-Q$. The electrons accelerate towards $+Q$ and neutralise the charges. The current lasts only for a very short while.



Fig. 3.1: Charges $+Q$ and $-Q$ put at the ends of a metallic cylinder. The electrons will drift because of the electric field created to neutralise the charges. The current thus will stop after a while unless the charges $+Q$ and $-Q$ are continuously replenished

Steady current: If the charges at the ends are continuously replenished, a **steady electric field** is maintained and a **continuous current** flows. Cells or batteries provide this mechanism.

Key Examination Points for Full Marks:

- In solid conductors, current is carried by **electrons**; in electrolytes, by **positive and negative ions**; in an ionised gas, by electrons and positive ions.
- Free charged particles exist naturally in the **ionosphere**.

Q.3 State Ohm's law. Derive $R = \rho l/A$ and define resistivity.

(3 Marks)

Ohm's law (G.S. Ohm, 1828): The current flowing through a conductor is directly proportional to the potential difference across its ends, provided its physical conditions (such as temperature) remain unchanged:

$$V \propto I \Rightarrow V = RI$$

R is the **resistance** of the conductor. **SI unit:** ohm (Ω); $1 \Omega = 1 \text{ V A}^{-1}$. **Dimensions:** $[M L^2 T^{-3} A^{-2}]$.

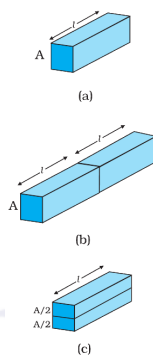


Fig. 3.2: Illustrating the relation $R = \rho l/A$ for a rectangular slab of length l and area of cross-section A

Dependence on length: Place two identical slabs (length l , area A) end to end (Fig. 3.2(b)). The same current I flows through both, and the potential difference across the combination is $2V$:

$$R_C = \frac{2V}{I} = 2R \Rightarrow R \propto l$$

Dependence on area: Cut a slab lengthwise into two halves of area $A/2$ (Fig. 3.2(c)). For the same V , each half carries $I/2$:

$$R_1 = \frac{V}{I/2} = 2R \Rightarrow R \propto \frac{1}{A}$$

Combining:

$$R \propto \frac{l}{A} \Rightarrow R = \rho \frac{l}{A}$$

Resistivity (ρ): The constant ρ that depends on the **material** of the conductor (and temperature) but **not on its dimensions**. It equals the resistance of a conductor of unit length and unit cross-sectional area. **SI unit:** $\Omega \text{ m}$. **Dimensions:** $[M L^3 T^{-3} A^{-2}]$.

Key Examination Points for Full Marks:

- R depends on the material **and** the dimensions; ρ depends only on the material (and temperature).
- **Conductivity:** $\sigma = 1/\rho$, SI unit S m^{-1} (siemens per metre).

Q.4 Define current density. Derive the vector form of Ohm's law, $\mathbf{j} = \sigma \mathbf{E}$. (2 Marks)

Current density ($\mathbf{j}$): The current per unit area taken normal to the current:

$$j = \frac{I}{A}$$

SI unit: A m^{-2} . It is a **vector**, directed along $\mathbf{E}$ (the direction of flow of positive charge). **Dimensions:** $[\text{L}^{-2} \text{A}]$.

Derivation: From Ohm's law and $R = \rho l / A$:

$$V = IR = \frac{I \rho l}{A}$$

If E is the uniform electric field in the conductor of length l , then $V = El$, and $I/A = j$:

$$El = j \rho l \Rightarrow E = j \rho$$

In vector form,

$$\vec{E} = \rho \vec{j} \quad \text{or} \quad \vec{j} = \sigma \vec{E}$$

where $\sigma = 1/\rho$ is the **conductivity**. This is the **vector (microscopic) form of Ohm's law**.

Q.5 What is drift velocity and relaxation time? Derive an expression for drift velocity. (3 Marks)

In the absence of a field: If there are N electrons with velocities $\vec{v}_i$, their average is zero because the directions are random:

$$\frac{1}{N} \sum_{i=1}^N \vec{v}_i = 0$$

With a field $\mathbf{E}$: Each electron accelerates:

$$\vec{a} = \frac{-e\vec{E}}{m}$$

Consider the i^{th} electron at time t . Let t_i be the time elapsed after its last collision and $\vec{v}_i$ its velocity just after that collision. Then its velocity at time t is

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

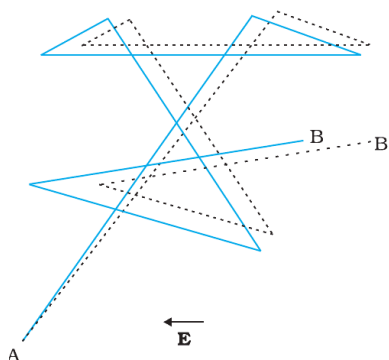


Fig. 3.3: A schematic picture of an electron moving from a point A to another point B through repeated collisions, and straight line travel between collisions (full lines). If an electric field is applied as shown, the electron ends up at point B' (dotted lines). A slight drift in a direction opposite the electric field is visible

Relaxation time (τ): The average time between successive collisions. The average of t_i over all electrons is τ .

Drift velocity: Averaging over all N electrons (the average of $\vec{v}_i$ is zero):

$$\vec{v}_d \equiv \left(\vec{V}_i \right)_{\text{average}} = \left(\vec{v}_i \right)_{\text{average}} - \frac{e\vec{E}}{m} \left(t_i \right)_{\text{average}} = 0 - \frac{e\vec{E}}{m} \tau$$

$$\vec{v}_d = -\frac{eE}{m}\tau$$

Drift velocity is the average velocity with which free electrons drift opposite to the applied electric field. Even though the electrons are accelerated, they move with an average velocity that is **independent of time** — this is the phenomenon of **drift**.

Key Examination Points for Full Marks:

- The drift speed is very small ($\sim 1 \text{ mm s}^{-1}$), while thermal speeds are $\sim 10^5 \text{ m s}^{-1}$ (electrons).
- The negative sign shows that electrons drift **opposite** to **E**.

Q.6 Derive the relation between current and drift velocity. Hence obtain σ and ρ . (3 Marks)

Consider a planar area A inside the conductor, normal to **E** (Fig. 3.4). Let n be the number of free electrons per unit volume.

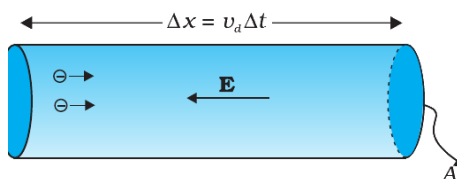


Fig. 3.4: Current in a metallic conductor. The magnitude of current density in a metal is the magnitude of charge contained in a cylinder of unit area and length v_d

In time Δt , all electrons within a distance $|v_d|\Delta t$ to the left of the area will cross it. The number of such electrons is $nA|v_d|\Delta t$. Each carries charge $-e$, so the charge crossing in time Δt is

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

Substituting $|v_d| = \frac{eE\tau}{m}$:

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

Since $I = |j|A$:

$$|j| = \frac{ne^2}{m}\tau|E| \quad \text{or} \quad \vec{j} = \frac{ne^2}{m}\tau\vec{E}$$

Comparing with $\vec{j} = \sigma\vec{E}$:

$$\sigma = \frac{ne^2\tau}{m}, \quad \rho = \frac{1}{\sigma} = \frac{m}{ne^2\tau}$$

Conclusion: This simple picture of electrical conduction **reproduces Ohm's law**, assuming τ and n are constant, independent of E .

Illustration (NCERT Example 3.1): For a copper wire of area $1.0 \times 10^{-7} \text{ m}^2$ carrying 1.5 A, with $n = 8.5 \times 10^{28} \text{ m}^{-3}$: $v_d = \frac{I}{neA} = 1.1 \times 10^{-3} \text{ m s}^{-1} = 1.1 \text{ mm s}^{-1}$. This is about 10^{-5} times the thermal speed of copper atoms and 10^{-11} times the speed of the electric field along the conductor ($3 \times 10^8 \text{ m s}^{-1}$).

Q.7 Define mobility. Why is current set up almost instantly though drift speed is small? (2 Marks)

Mobility (μ): The magnitude of drift velocity per unit electric field:

$$\mu = \frac{|v_d|}{E}$$

Since $v_d = \frac{e\tau E}{m}$:

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

SI unit: $\text{m}^2 \text{V}^{-1} \text{s}^{-1}$ ($= 10^4$ times the practical unit $\text{cm}^2 \text{V}^{-1} \text{s}^{-1}$). Mobility is positive. **Dimensions:** $[\text{M}^{-1} \text{T}^2 \text{A}]$.

Charge carriers: In metals — electrons; in an ionised gas — electrons and positive ions; in an electrolyte — positive and negative ions.

Why current is established instantly (NCERT Example 3.2):

- (a) The electric field is set up throughout the circuit almost **instantly** (at the speed of light), causing a local electron drift at every point. Current does not wait for electrons to travel from one end to the other.
- (b) Electrons accelerate only until they collide with ions; then they lose their drift speed and start again. On average, they acquire only a **steady drift speed**.
- (c) A large current flows despite a small drift speed because the **electron number density is enormous** ($\sim 10^{29} \text{m}^{-3}$).
- (d) Drift does not mean all free electrons move in the same direction; the drift velocity is **superposed** on their large random velocities.
- (e) Between collisions, electron paths are straight lines without a field, and **curved** (in general) with a field.

Q.8 What are the limitations of Ohm's law? Give examples of non-ohmic devices. (2 Marks)

Ohm's law is valid for a large class of materials, but it is **not a fundamental law of nature**. The deviations are of the following types:

(a) **V ceases to be proportional to I** (Fig. 3.5). The V–I graph is not a straight line.

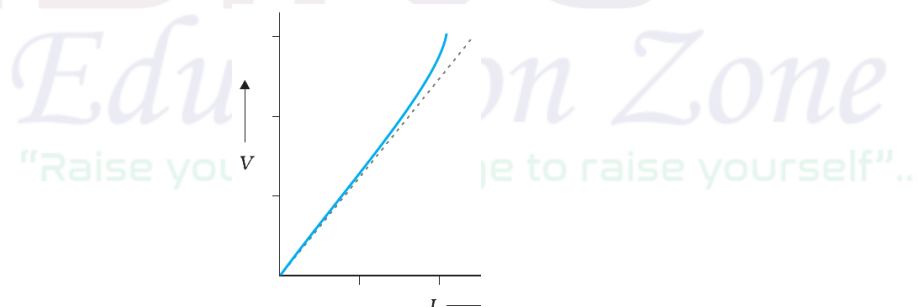


Fig. 3.5: The dashed line represents the linear Ohm's law. The solid line is the voltage V versus current I for a good conductor

(b) **The relation between V and I depends on the sign of V.** Reversing V (keeping its magnitude) does not give the same magnitude of current in the opposite direction (Fig. 3.6). Example: a **diode**.

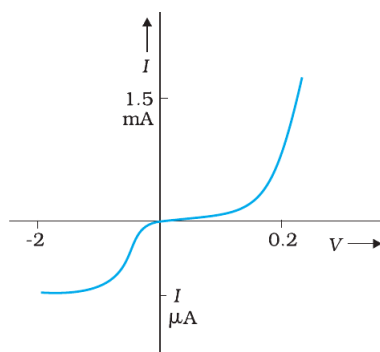


Fig. 3.6: Characteristic curve of a diode. Note the different scales for negative and positive values of the voltage and current

(c) **The relation between V and I is not unique** — there is more than one value of V for the same I (Fig. 3.7). Example: **GaAs** (gallium arsenide).

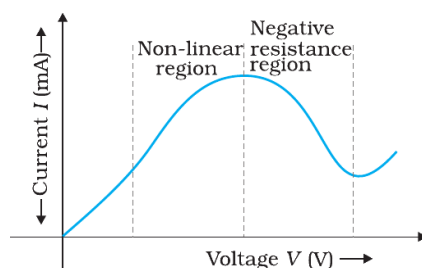


Fig. 3.7: Variation of current versus voltage for GaAs

Key Examination Points for Full Marks:

- Materials and devices that do not obey Ohm's law (non-ohmic) are widely used in electronic circuits.
- A **rectifier** combines features (a) and (b); GaAs shows feature (c).
- $V = IR$ **defines** resistance for any device. Ohm's law asserts that R is **independent of V** (i.e. the I - V plot is linear).

Q.9 Explain the resistivity of materials and its dependence on temperature. (3 Marks)

Classification by resistivity:

Material	Resistivity	Example
Conductors (metals)	Low: 10^{-8} to $10^{-6} \Omega \text{ m}$	Copper, silver, aluminium
Semiconductors	Intermediate	Si, Ge
Insulators	Very high: 10^{18} times metals or more	Ceramic, rubber, plastics

The resistivity of semiconductors **decreases** with rising temperature and can be reduced by adding small amounts of suitable impurities.

Temperature dependence (metals): Over a limited range of temperature,

$$\rho_T = \rho_0 [1 + \alpha (T - T_0)]$$

where ρ_T and ρ_0 are the resistivities at T and reference temperature T_0 . α is the **temperature coefficient of resistivity**, with dimension $(\text{temperature})^{-1}$. For metals, α is **positive**.

α is the fractional increase in resistivity per unit rise in temperature: $\alpha = \frac{\rho_T - \rho_0}{\rho_0 (T - T_0)}$.

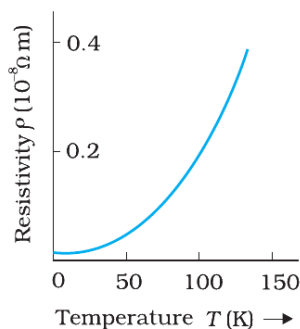


Fig. 3.8: Resistivity ρ_T of copper as a function of temperature T

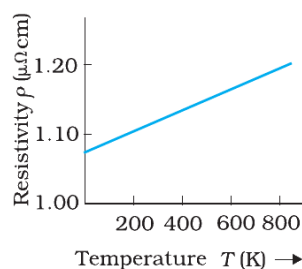


Fig. 3.9: Resistivity ρ of nichrome as a function of absolute temperature T

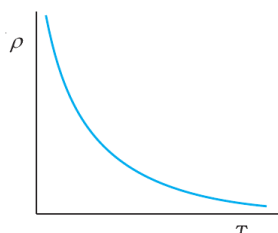


Fig. 3.10: Temperature dependence of resistivity for a typical semiconductor

- **Copper (metal):** ρ increases with T ; the graph deviates from a straight line at low temperatures (Fig. 3.8).
- **Nichrome, manganin, constantan:** very **weak** dependence on temperature (Fig. 3.9) — used in **standard resistors**.
- **Semiconductors:** ρ **decreases** with rising temperature (Fig. 3.10).

Explanation using $\rho = \frac{m}{ne^2\tau}$:

- **Metals:** n does not change appreciably with temperature. As T rises, electrons collide more often, so τ **decreases** and ρ **increases**.
- **Insulators and semiconductors:** n **increases** with temperature. This more than compensates for the decrease in τ , so ρ **decreases**.

Q.10 Derive the expression for electrical power. Why is power transmitted at high voltage? (3 Marks)

Consider a conductor AB in which current I flows from A to B, with $V(A) > V(B)$ and potential difference $V = V(A) - V(B)$. In time Δt , charge $\Delta Q = I\Delta t$ moves from A to B.

Change in potential energy:

$$\Delta U_{pot} = \Delta Q [V(B) - V(A)] = -\Delta Q V = -IV\Delta t < 0$$

If the charges moved without collisions, their kinetic energy would increase: $\Delta K = -\Delta U_{pot} = IV\Delta t$. But charge carriers move with a steady drift velocity because of **collisions**; the energy gained is shared with the atoms, which **vibrate more** — the conductor **heats up**. The energy dissipated as heat:

$$\Delta W = IV\Delta t$$

Power (energy dissipated per unit time):

$$P = \frac{\Delta W}{\Delta t} = IV = I^2 R = \frac{V^2}{R}$$

This is the **ohmic loss**. It heats the coil of an electric bulb to incandescence. The power is supplied by the external source, e.g. the chemical energy of a cell (Fig. 3.11).

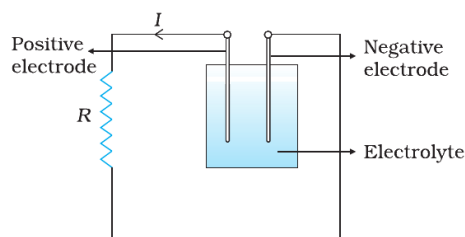


Fig. 3.11: Heat is produced in the resistor R which is connected across the terminals of a cell. The energy dissipated in the resistor R comes from the chemical energy of the electrolyte

Power transmission: A device needs power $P = VI$, delivered through cables of resistance R_c . The power wasted in the cables:

$$P_c = I^2 R_c = \frac{P^2 R_c}{V^2}$$

For a given P , $P_c \propto \frac{1}{V^2}$. So power is transmitted at **very high voltage** (low current) to minimise loss. A **transformer** at the other end lowers the voltage for safe use.

SI unit of power: watt (W). $1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$.

Q.11 Define emf and internal resistance of a cell. Derive the relation $V = \mathcal{E} - Ir$. (3 Marks)

Cell: A device that maintains a steady current. It has two electrodes, positive (P) and negative (N), immersed in an electrolyte. The positive electrode has a potential difference V_+ ($V_+ > 0$) with the adjacent electrolyte (point A), and the negative electrode has $-V_-$ ($V_- \geq 0$) relative to the electrolyte at B.

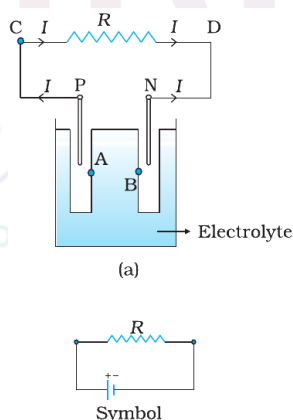


Fig. 3.12: (a) Sketch of an electrolyte cell with positive terminal P and negative terminal N. (b) The symbol for a cell

Electromotive force (emf, $\mathcal{E}$): When no current flows, the potential difference between P and N:

$$\mathcal{E} = V_+ - (-V_-) = V_+ + V_- > 0$$

emf is the potential difference between the positive and negative electrodes in an open circuit (no current through the cell). It is **not a force**; the name is used for historical reasons.

Internal resistance (r): The resistance offered by the electrolyte to the flow of current inside the cell.

Terminal voltage: When a resistor R is connected, current I flows through the cell from N to P (through the electrolyte, from B to A). The potential difference between P and N is

$$V = V_+ + V_- - Ir \Rightarrow V = \mathcal{E} - Ir$$

Also $V = IR$, so

$$IR = \mathcal{E} - Ir \Rightarrow I = \frac{\mathcal{E}}{R + r}$$

Key Examination Points for Full Marks:

- In an **open circuit** ($I = 0$), $V = \varepsilon$.
- **Maximum current** ($R = 0$, short circuit): $I_{max} = \varepsilon/r$. In practice, the allowed current is much lower to avoid damaging the cell.
- While **charging** a cell (current from P to N inside), $V = \varepsilon + Ir$.
- The internal resistance of **dry cells** is much higher than that of common electrolytic cells.

Q.12 Derive the equivalent emf and internal resistance of two cells in series. (2 Marks)

Consider two cells (emf $\varepsilon_1, \varepsilon_2$; internal resistances r_1, r_2) in series, with the negative terminal of the first joined to the positive terminal of the second (Fig. 3.13).

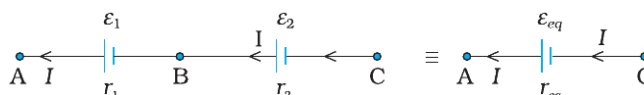


Fig. 3.13: Two cells of emf's ε_1 and ε_2 in the series. r_1, r_2 are their internal resistances. For connections across A and C, the combination can be considered as one cell of emf ε_{eq} and an internal resistance r_{eq}

$$V_{AB} = V(A) - V(B) = \varepsilon_1 - Ir_1, \quad V_{BC} = V(B) - V(C) = \varepsilon_2 - Ir_2$$

$$V_{AC} = V_{AB} + V_{BC} = (\varepsilon_1 + \varepsilon_2) - I(r_1 + r_2)$$

Replacing by a single cell, $V_{AC} = \varepsilon_{eq} - Ir_{eq}$. Comparing:

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

If the two negatives are connected (one cell reversed): $\varepsilon_{eq} = \varepsilon_1 - \varepsilon_2$ ($\varepsilon_1 > \varepsilon_2$), and $r_{eq} = r_1 + r_2$ still.

For n cells in series:

- The equivalent emf is the **sum** of the individual emfs (with a negative sign for any reversed cell).
- The equivalent internal resistance is the **sum** of the internal resistances.

Q.13 Derive the equivalent emf and internal resistance of two cells in parallel. (3 Marks)

Consider two cells connected in parallel, positive terminals joined at B_1 and negative terminals at B_2 (Fig. 3.14). I_1 and I_2 are the currents leaving the positive electrodes.

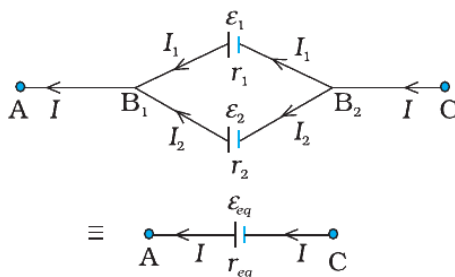


Fig. 3.14: Two cells in parallel. For connections across A and C, the combination can be replaced by one cell of emf ε_{eq} and internal resistance r_{eq}

At B_1 : $I = I_1 + I_2$. Let $V = V(B_1) - V(B_2)$. Then for each cell:

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

So

$$I = I_1 + I_2 = \frac{\varepsilon_1 - V}{r_1} + \frac{\varepsilon_2 - V}{r_2} = \left(\frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2} \right) - V \left(\frac{1}{r_1} + \frac{1}{r_2} \right)$$

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

Comparing with $V = \varepsilon_{eq} - Ir_{eq}$:

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

Simpler form:

$$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2}, \quad \frac{\varepsilon_{eq}}{r_{eq}} = \frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2}$$

For n cells in parallel:

$$\frac{1}{r_{eq}} = \frac{1}{r_1} + \dots + \frac{1}{r_n}, \quad \frac{\varepsilon_{eq}}{r_{eq}} = \frac{\varepsilon_1}{r_1} + \dots + \frac{\varepsilon_n}{r_n}$$

If the negative terminal of the second cell is connected to the positive of the first, replace $\varepsilon_2 \rightarrow -\varepsilon_2$.

Q.14 State and explain Kirchhoff's rules.

(3 Marks)

For complicated circuits, series and parallel formulae are not enough. Two rules given by **Gustav Robert Kirchhoff** are used.

Sign convention: Label each current with a symbol and an arrow. If a current comes out negative, it actually flows opposite to the arrow. For a cell, going from P to N gives $V = \varepsilon - Ir$ (current from N to P inside) or $V = \varepsilon + Ir$ (current from P to N inside).

(a) Junction rule (first rule): At any junction, the **sum of the currents entering the junction is equal to the sum of the currents leaving the junction**:

$$\sum I = 0$$

Basis: Conservation of charge. For steady currents, no charge accumulates at any junction or point in a line.

(b) Loop rule (second rule): The **algebraic sum of changes in potential around any closed loop** involving resistors and cells is **zero**:

$$\sum \Delta V = 0 \quad \text{or} \quad \sum IR = \sum \varepsilon$$

Basis: Conservation of energy. Electric potential depends only on the location of a point, so returning to the starting point gives zero total change.

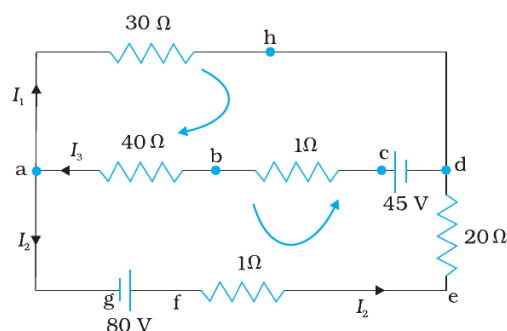


Fig. 3.15: At junction *a* the current leaving is $I_1 + I_2$ and current entering is I_3 . The junction rule says $I_3 = I_1 + I_2$. At point *h* current entering is I_1 . There is only one current leaving *h* and by junction rule that will also be I_1 . For the loops 'ahdcba' and 'ahdefga', the loop rules give $-30I_1 + 45 = 0$ and $-30I_1 + 21I_2 - 80 = 0$

Key Examination Points for Full Marks:

- The junction rule applies equally well to a **point in a line** (not just a junction).
- Bending or reorienting the wire does not change the validity of the junction rule.
- Apply the loop rule to as many **independent** loops as there are unknowns.

Q.15 What is a Wheatstone bridge? Derive its balance condition using Kirchhoff's rules. (3 Marks)

Wheatstone bridge: An arrangement of four resistors R_1, R_2, R_3, R_4 (Fig. 3.18). A source is connected across one pair of opposite points (A and C — the **battery arm**), and a galvanometer G between the other two (B and D — the **galvanometer arm**).

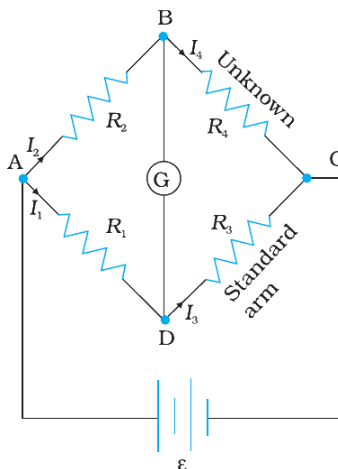


Fig. 3.18: The Wheatstone bridge

Balanced bridge: The resistors are such that the galvanometer current $I_g = 0$.

Derivation: Assume the cell has no internal resistance. With $I_g = 0$, the junction rule at D and B gives

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

Loop ADBA:

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

Loop CBDC (using $I_3 = I_1, I_4 = I_2$):

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

Hence the **balance condition**:

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

Use: To find an **unknown resistance** R_4 : keep known R_1 and R_2 , and vary R_3 until the galvanometer shows **null deflection**. Then

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

R_4 is the **unknown arm**; R_3 is the **standard arm**. A practical device using this principle is the **meter bridge**.

Key Examination Points for Full Marks:

- At balance, B and D are at the **same potential**, so no current flows through G.
- At balance, the galvanometer and cell may be **interchanged** without disturbing the balance.

Formula Sheet — Current Electricity

Quantity	Formula	SI Unit
Current	$I = \frac{q}{t}; I = \frac{dQ}{dt}$	A
Current and drift velocity	$I = neAv_d$	A
Current density	$j = \frac{I}{A} = nev_d; \vec{j} = \sigma \vec{E}$	A m ⁻²
Ohm's law	$V = IR$	V
Resistance	$R = \rho \frac{l}{A}$	Ω
Drift velocity	$v_d = \frac{eE\tau}{m}$	m s ⁻¹
Mobility	$\mu = \frac{v_d}{E} = \frac{e\tau}{m}$	m ² V ⁻¹ s ⁻¹
Conductivity	$\sigma = \frac{1}{\rho} = \frac{ne^2\tau}{m}$	S m ⁻¹
Resistivity	$\rho = \frac{m}{ne^2\tau}$	Ω m
Temperature dependence	$\rho_T = \rho_0 [1 + \alpha (T - T_0)];$ $R_T = R_0 (1 + \alpha \Delta T)$	—
Power	$P = VI = I^2 R = \frac{V^2}{R}$	W
Transmission loss	$P_c = \frac{P^2 R_c}{V^2}$	W
Terminal voltage	$V = \varepsilon - Ir$ (discharging); $\varepsilon + Ir$ (charging)	V
Current from a cell	$I = \frac{\varepsilon}{R + r}; I_{max} = \frac{\varepsilon}{r}$	A
Cells in series	$\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2, r_{eq} = r_1 + r_2$	—
Cells in parallel	$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2}, \frac{\varepsilon_{eq}}{r_{eq}} = \frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2}$	—
Resistors in series	$R = R_1 + R_2 + \dots$	Ω
Resistors in parallel	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$	Ω
Wheatstone bridge balance	$\frac{R_1}{R_2} = \frac{R_3}{R_4}$ (opposite arms in ratio)	—

Dimensions: Resistance [M L²T⁻³A⁻²]; resistivity [M L³T⁻³A⁻²]; conductivity [M⁻¹L⁻³T³A²]; mobility [M⁻¹T²A]; current density [L⁻²A].

NEET / JEE Quick Points and Tricks

- Stretching a wire** (volume constant): if the length becomes n times, R becomes n^2 times. If the radius becomes $1/n$, R becomes n^4 times.
- Cutting a wire** of resistance R into n equal parts and joining them in parallel: $R_{eq} = R/n^2$.
- Drift velocity** is independent of the wire's area for a given E , but for a given current, $v_d \propto 1/A$. In a wire of non-uniform cross-section, I is the same everywhere; j , E and v_d are larger where the wire is thinner.
- Doubling the length** at the same applied V : E halves, so v_d halves.

5. **Maximum power transfer:** the power in the external resistor is maximum when $R = r$; then $P_{max} = \frac{\varepsilon^2}{4r}$ and efficiency is 50%.
6. **Mixed grouping** (m rows of n cells each in series): $I = \frac{n\varepsilon}{R + nr/m}$; maximum when $R = nr/m$.
7. **Bulbs:** In series, the bulb of **lower wattage** (higher R) glows brighter. In parallel, the bulb of **higher wattage** glows brighter. $R = V_{rated}^2 / P_{rated}$.
8. **Series vs parallel heating:** for the same supply, two heaters in parallel boil water 4 times faster than in series. $t_{series} = t_1 + t_2$; $\frac{1}{t_{parallel}} = \frac{1}{t_1} + \frac{1}{t_2}$.
9. **Colour code:** B B R O Y G B V G W = 0 to 9 ("BB ROY of Great Britain has a Very Good Wife"). Gold $\pm 5\%$, silver $\pm 10\%$, no band $\pm 20\%$.
10. **Cube of 12 equal resistors R:** across a body diagonal $5R/6$; across a face diagonal $3R/4$; across an edge $7R/12$.
11. **Balanced Wheatstone bridge:** the middle resistor carries **no current** and can be removed. Check the ratio of opposite arms first.
12. **Infinite ladder** of R in series and R in parallel: $R_{eq} = \frac{(1 + \sqrt{5})}{2} R$.
13. **Terminal voltage > emf** only while the cell is being **charged**.
14. **Resistivity depends on material and temperature, not on dimensions.** Resistance depends on all three.

