JEE Main Physics

Short Notes

Current Electricity

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Current Electricity is an important topic from JEE Main / JEE Advanced Exam Point of view. Every year there are 1-3 questions asked from this topic. This short notes on Current Electricity will help you in revising the topic before the JEE Main & IIT JEE Advanced Exam.

Current Electricity

Electric Current

The rate of flow of charge through a surface area is known as current. It is the convention that the direction of current is opposite to the direction of flow of electron (negative charge).

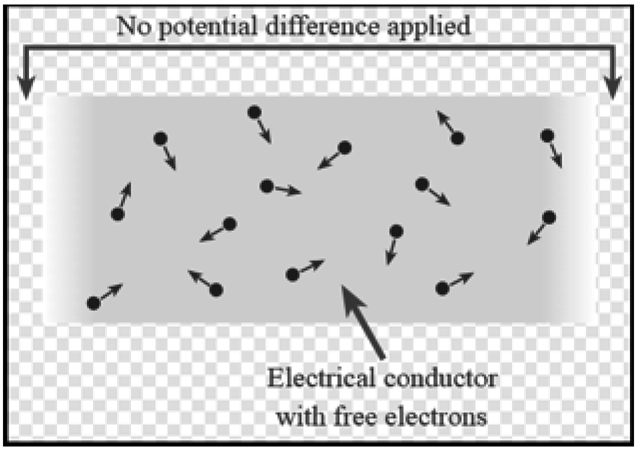
Le the charge ΔQ is passing through a surface in time Δt then the current is, $I = \frac{\Delta Q}{\Delta t}$

Similarly, Instantaneous current is $I = \frac{dQ}{dt}$

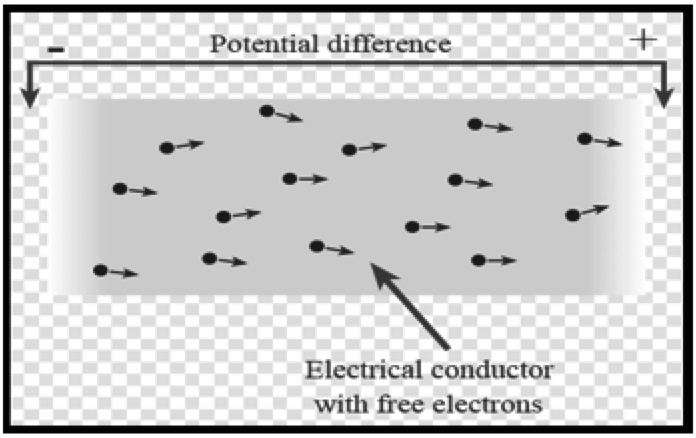
SI unit of Electric current is Ampere.

Electric current in conductor

The electric charges respond to Electric field and experience a force. When there is no electric field applied across the conductor the electrons are in random thermal motion inside the conductor. So, on an average basis the number of electrons moving in any direction is the same as the number of electrons moving in the opposite direction. So, there will be no net electric current.



As the field is applied the electrons respond to Electric field and experience a force and tend to align themselves in the direction opposite to the direction of field. From the convention the direction of current flow is taken opposite to the direction of flow of electrons.



Ohm's Law

Ohm's Law It states that the current flowing through the conductor is directly proportional to the applied potential difference across the ends of the conductor under constant physical conditions.

$$I \propto V$$

$$V = IR$$

Here R is the constant of proportionality which defines the resistance offered by the conductor.

Resistance: It is the property of the material which restricts the flow of the current through the conductor. It depends on the temperature and the physical dimensions of the conductor.

Its SI unit is Ohm (Ω)

The resistance of the conductor depends on the physical dimensions of the conductor,

$$R \propto l$$

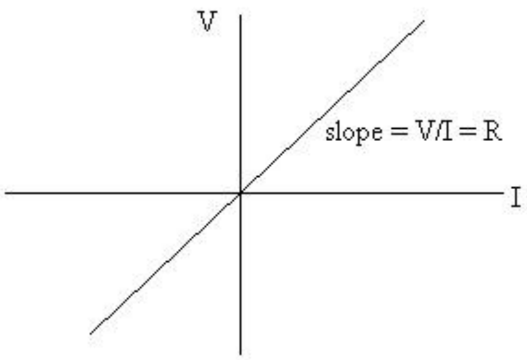
$$R \propto \frac{1}{A}$$

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

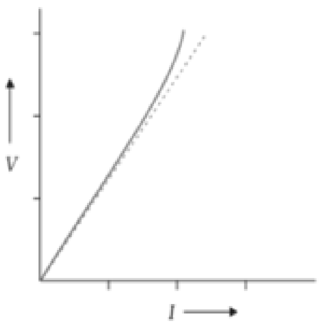
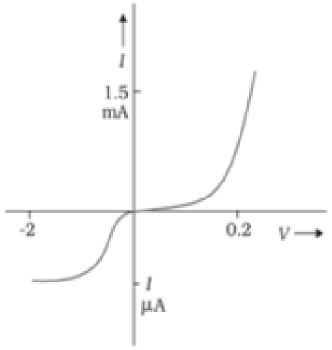
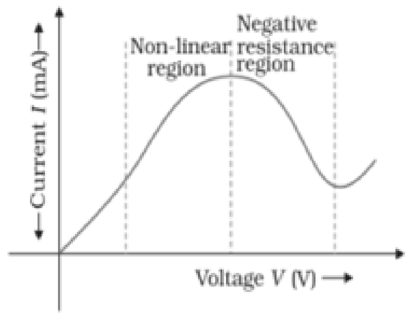
Here, l is the length of the conductor, A is the cross-sectional area and ρ is the resistivity of the conductor.

V-I characteristics of OHMIC Material:

Linear V-I characteristics of an ohmic material.



V-I characteristics of Non-Ohmic Material

		
a). At high temperature voltage V ceases to be proportional to I and deviates from the linearity.	b) In diodes reversing the direction of V keeping its magnitude fixed, does not produce a current of the same magnitude as I in the opposite direction.	c) For Germanium, Arsenic the material shows two values of current for same Voltage defying the linear characteristics of Ohms Law

Drift Velocity and Resistivity

Drift Velocity When the charged particles move around in a conductor because of the interparticle collisions, their motion is in a haphazard manner. Therefore, the average speed of the particle in the conductor is known as the drift velocity.

The current due to this drift factor of electrons in a charged is called as the drift current.

$$v_d = -\frac{eE}{m}\tau$$

Here v_d is the drift velocity, e is the electronic charge, E is the applied electric field across the conductor, m is the mass of the charged particle and τ is the relaxation time.

Mobility The drift velocity per unit electric field is known as the mobility. It tells that how efficiently the charged particles can move freely or its ability to move freely.

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

$$\mu = \frac{eE}{mE}\tau$$

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

Relation between current and Drift velocity

The charge flowing through an area A is

$$Q = n \times e \times A \times (v_d \times \Delta t)$$

$$\frac{Q}{\Delta t} = neAv_d$$

$$I_{avg} = neAv_d$$

Here, n is the number of charges per unit volume, e is the electric charge, v_d is the drift velocity, A is the cross-sectional area and Δt is the time interval.

Relation between current and Mobility

$$v_d = \mu E$$
$$I = neAv_d$$
$$I_{avg} = (neAE)\,\mu$$

Electrical Conductivity: It is the property of the material that allows the flow of current through the conductor. Mathematically it is the reciprocal of the resistivity.

Resistivity and Conductivity

From the definition of drift current,

$$I = neAv_d$$
$$I = \frac{ne^2A}{m}\tau|E|$$
$$J|A = \frac{ne^2A}{m}\tau|E| \qquad \ldots\ldots\left(J = \frac{I}{A}\right)$$
$$|J| = \frac{ne^2}{m}\tau|E|$$
$$J = \sigma E \qquad \ldots\ldots\ldots\ldots\left(\sigma = \frac{ne^2}{m}\tau\right)$$

Here J is the current density i.e. current per unit area and $\left(\sigma = \frac{ne^2}{m}\tau\right)$ is the conductivity of the material.

The resistivity of the material is the reciprocal of the conductivity.

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

Electrical resistivity and Conductivity Electrical resistivity of a material is the property of the material that opposes the flow of the current. It's also known as the specific resistance of the material.

$$\rho = \frac{AR}{l}$$

Electrical energy and power

If in time interval Δt, $\Delta Q = I\Delta t$ amount of charge flows form End A of the conductor to end B of the conductor then the potential energy at both the ends will be QV_A and QV_B.

The total energy in the conductor is the change in the potential energy across the conductor ends.

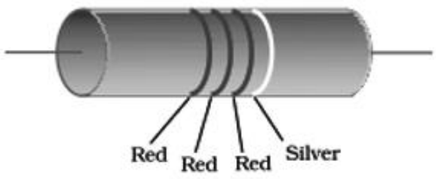
$$E = Q(V_B - V_A)$$
$$E = -Q\Delta V$$

Electric Power: The amount of energy dissipated per unit time as heat is known as the electrical power of the conductor.

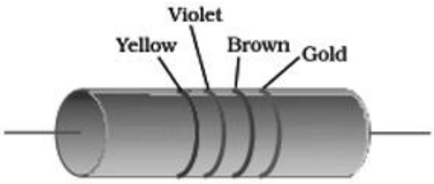
$$\text{Energy Disssipated} = W = IV\Delta t$$
$$W = IV\Delta t$$
$$\frac{W}{\Delta t} = IV \qquad \left(\frac{W}{\Delta t} = P\right)$$
$$P = IV = I^2R = \frac{V^2}{R} \qquad (V = IR)$$

Resistor and their combination

Carbon Resistors Carbon resistors are comparatively small inexpensive therefore it has widespread use in electronic circuits. Carbon resistors are small in size and hence their standards are given using a colour code.



(a)

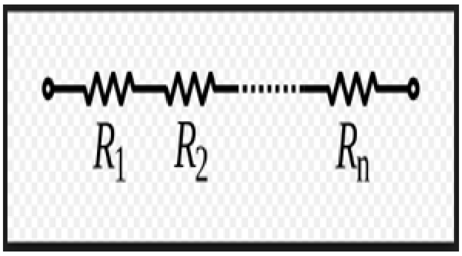


Colour Codes for Carbon Resistors

Colour	Number	Multiplier	Tolerance (%)
Black	0	1	
Brown	1	10^1	
Red	2	10^2	
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	
Gold		10^{-1}	5
Silver		10^{-2}	10
No colour			20

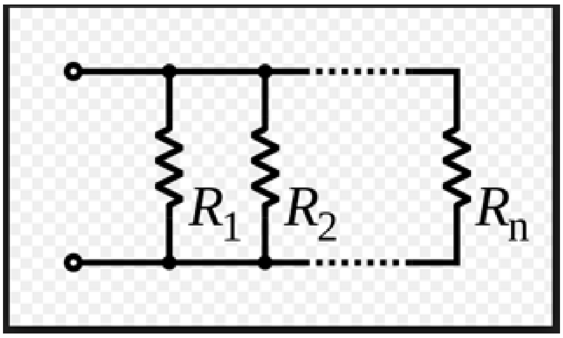
Combination of resistors:

Series Combination:



$$R_{eq} = R_1 + R_2 + R_3 + \ldots.. + R_n$$

Parallel Combination:



$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots \frac{1}{R_n}$$

Temperature dependence of resistance:

The resistance of a conductor has a linear dependency on the temperature as

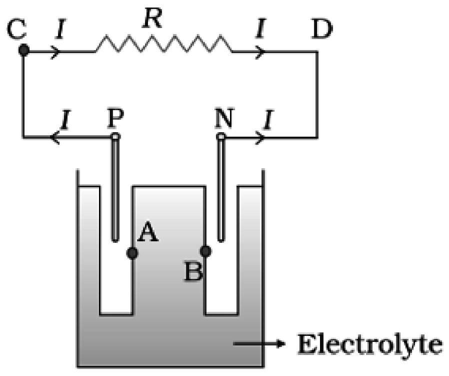
$$R = R_0\left(1+\alpha\left(T-T_0\right)\right)$$
$$\rho = \rho_0\left(1+\alpha\left(T-T_0\right)\right)$$

where α is the temperature coefficient.

Cell and their Combination

Potential difference and potential of Cell

A cell has two electrodes one positive (P) and one negative (N). Both are immersed in an electrolytic solution. In the solution, the electrodes interchange charges with the electrolyte. The positive electrode has a potential difference between itself and the electrolyte solution similarly, the negative electrode develops a negative potential (V– (V– ≥0) relative to the electrolyte. When there is no current, the electrolyte has the same potential throughout, so that the potential difference between the electrodes is known as the Emf of the battery.



$$\varepsilon = V_+ - (-V_-)$$
$$\varepsilon = V_+ + V_-$$

Emf is the potential difference between the positive and negative electrodes when no current is flowing through the cell an open circuit,

This difference is called the electromotive force (Emf) of the cell and is denoted by ε.

If the circuit is closed then, $\varepsilon = V - ir$

Here, r is the internal resistance of the cell.

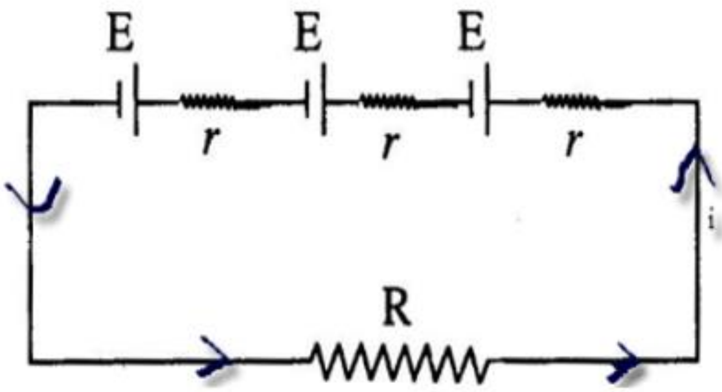
$$\varepsilon = V - ir$$
$$\varepsilon = IR - Ir$$
$$I = \frac{\varepsilon}{R - r}$$

The internal resistance of the cell is the resistance offered by the electrolyte inside the cell.

The maximum current flowing in the circuit is:

$$I_{\max} = \frac{\varepsilon}{0 + r} = \frac{\varepsilon}{r}$$

Combination of cells in series:



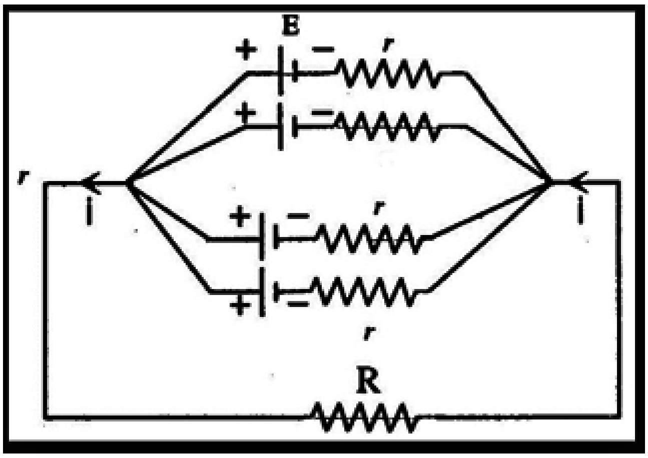
If *n* numbers of cells are connected in series

$$V = \varepsilon_{eq} - Ir_{eq}$$

$$\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 ...... + \varepsilon_n$$

$$r_{eq} = r_1 + r_2 + ... r_n$$

Combination of cells in parallel



If *n* numbers of cells are connected in parallel

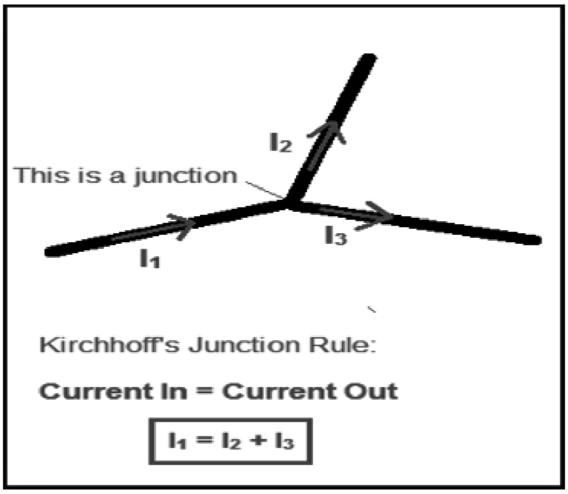
$$V = \varepsilon_{eq} - Ir_{eq}$$

$$\frac{\varepsilon_{eq}}{r_{eq}} = \frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2} + \frac{\varepsilon_3}{r_3} ...... + \frac{\varepsilon_n}{r_n}$$

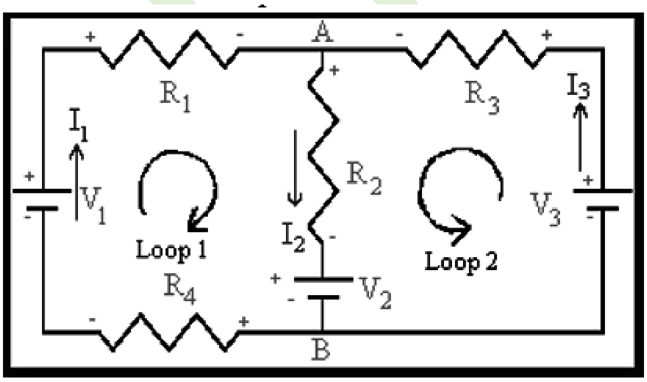
$$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_2} + ... + \frac{1}{r_n}$$

Kirchhoff's Law

1. Junction rule: At any junction, the sum of the currents entering the junction is equal to the sum of currents leaving the junction.

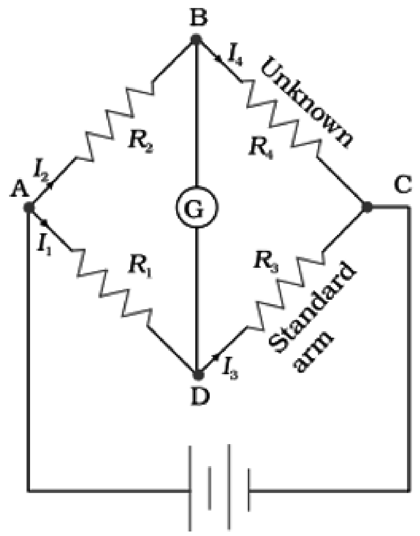


2. Loop rule: The algebraic sum of changes in potential around any closed loop involving resistors and cells in the loop is zero.



Wheatstone bridge, Meter Bridge, and Potentiometer

Wheatstone bridge

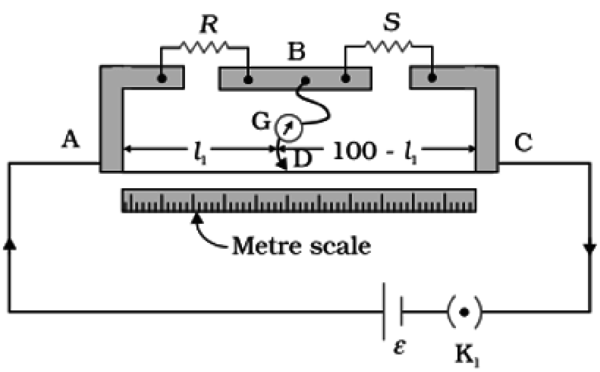


The above shown arrangement is a case of Wheatstone bridge.

For balanced condition: $\frac{R_1}{R_2} = \frac{R_3}{R_4}$ the current in the arm *BD* is zero, i.e. there will be no deflection in the galvanometer *G*.

Wheat stone bridges are used in calculation of unknown resistances.

Meter Bridge



It consists of a wire of length *1m*. and of uniform cross-sectional area strained tight and fastened between two thick metallic strips fixed at right angles.

The end points are connected to a cell through a key and one end of a galvanometer is connected to the metallic strip midway between the two gaps. The other end of the galvanometer is connected to a 'jockey' as in the figure.

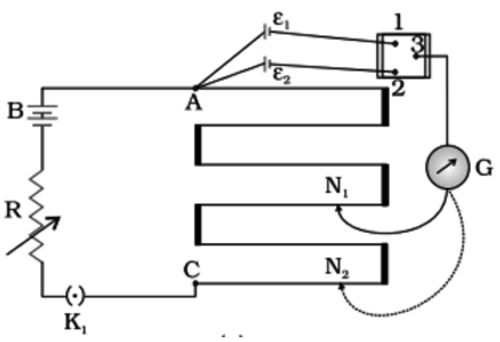
It uses the balanced Wheatstone bridge to determine the unknown resistance:

$$\frac{R}{S} = \frac{l_1}{100 - l_1}$$

$$R = S\frac{l_1}{100 - l_1}$$

Potentiometer

An instrument which has several metre-long wire connected across a cell. The potentiometer draws no current from the voltage source is measured because it is unaffected by the internal resistance of the source. It is used to compare the Emf's of a cell and the unknown internal resistance of the cell.



Principle: When a constant current flow through a uniform cross sectional wire the potential difference between two points is directly proportional to the length of the wire between the two points.

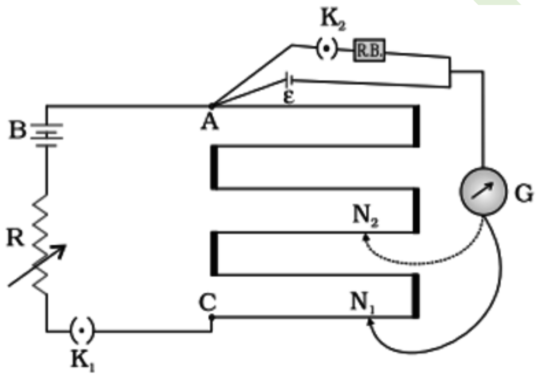
Applications of Potentiometer

Comparing the Emf of the cell: The Emf of a cell is compared by observing the balancing length l.

From the principle:

$$\varepsilon \propto l$$
$$\varepsilon = kl$$
$$\varepsilon_1 = kl_1$$
$$\varepsilon_2 = kl_2$$
$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{kl_1}{kl_2} = \frac{l_1}{l_1}$$

Comparing the Internal resistance of the cell:



As it draws no current from voltage source the internal resistance of any cell is measured using the potentiometer by finding the balancing lengths for the cell.

$$r = R\left(\frac{l_1}{l_2} - 1\right)$$

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