

**Class XII: Physics**  
**Ch 3: Current Electricity**

**Chapter Notes**

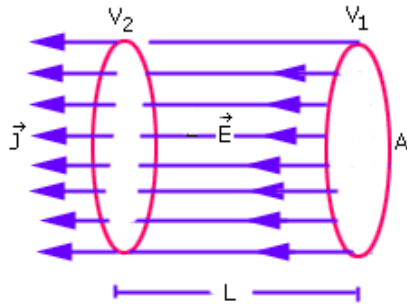
**Top Concepts**

1. Current through a given area of a conductor is the net charge passing per unit time through the area.
2. The current density vector  $\vec{j}$  gives current per unit area flowing through area ( $\Delta A$ ) when it is held normal to the direction of charge flow. Note that the direction of  $\vec{j}$  is in the direction of current flow.
3. Drift speed, which is the magnitude of this velocity, is enormously small as compared to the thermal speed, which is not a vector and is much larger.
4. When a conducting substance is brought under the influence of an electric field  $\vec{E}$ , free charges (e.g. free electrons in metals) move under the influence of this field in such a manner, that the current density  $\vec{j}$  due to their motion is proportional to the applied electric field.

$$\vec{j} = \sigma \vec{E}$$

where  $\sigma$  is a constant of proportionality called electrical conductivity.

This statement is one possible form of Ohm's law.



If we consider a cylindrical chunk of such a material with cross sectional area  $A$  and length  $L$  through which a current is passing along the length and normal to the area  $A$ , then, since  $\vec{j}$  and  $\vec{E}$  are in the same direction,

$$J = \sigma E$$

$$JAL = \sigma ELA$$

where  $A$  is cross sectional area and  $L$  is length of the material through which a current is passing along the length, normal to the area  $A$ .

But,  $JA = I$ , the current through the area  $A$  and  $EL = V_1 - V_2$ , the potential difference across the ends of the chunk denoting  $V_1 - V_2$  as  $V$ , this gives:

$$V = \frac{IL}{\sigma A} = RI$$

$$\text{where } R = \frac{L}{\sigma A}$$

is called resistance of the material.

In this form, **Ohm's law** can be stated as a linear relationship between the potential drop across a substance and the current passing through it.

R is measured in ohm ( $\Omega$ ), where

$$1\Omega = 1V/A$$

5. Emf (Electromotive force) is the name given to a non-electrostatic agency. Typically, it is a battery, in which a chemical process achieves this task of doing work in driving the positive charge from a low potential to a high potential.

The effect of such a source is measured in terms of work done per unit charge in moving a charge once around the circuit. This is denoted by

$\epsilon$ .

6. Metals have low resistivity: Range of  $\rho$  varies from  $10^{-8}\Omega\text{ m}$  to  $10^{-6}\Omega\text{ m}$ .

Insulators like glass and rubber have high resistivity: Range of  $\rho$  varies from  $10^{22}$  to  $10^{24}$  times greater than that of metals.

Semiconductors like Si and Ge lie roughly in the middle range of resistivity on a logarithmic scale.

7. Current density  $j$  gives the amount of charge flowing per second per unit area normal to the flow.

$$J = nq v_d$$

where  $n$  is the number density (number per unit volume) of charge carriers each of charge  $q$  and  $v_d$  is the drift velocity of the charge carriers. For electrons  $q = -e$ . If  $j$  is normal to a cross-sectional area  $A$  and is constant over the area, the magnitude of the current  $I$  through the area is  $nev_d A$ .

8. Ohm's law is obeyed by many substances, but it is not a fundamental law of nature. It fails if
- V depends on I non-linearly. Example is when  $\rho$  increases with I (even if temperature is kept fixed).
  - The relation between V and I depends on the sign of V for the same absolute value of V.
  - The relation between V and I is non-unique. For e.g., GaAs
- An example of (a) & (b) is of a rectifier

9. When a source of emf  $\epsilon$  is connected to an external resistance R, the voltage  $V_{\text{ext}}$  across R is given by

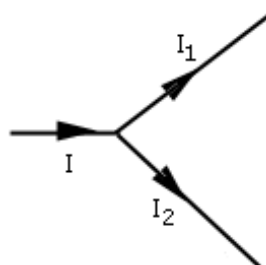
$$V_{\text{ext}} = IR = \frac{\epsilon}{R + r}R$$

where r is the internal resistance of the source.

10. Kirchhoff's Rules –

**Kirchhoff's First Rule:**

At any junction of several circuit elements, the sum of currents entering the junction must equal the sum of currents leaving it.



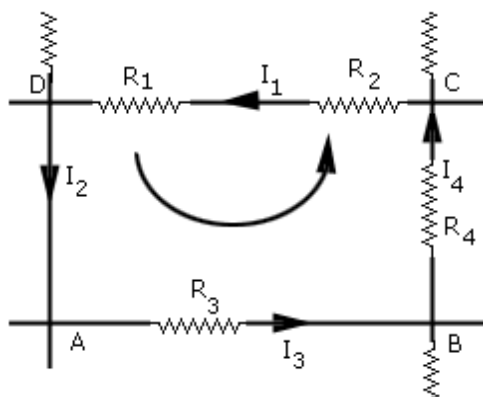
In the above junction, current I enters it and currents  $I_1$  and  $I_2$  leave it.

Then,  $I = I_1 + I_2$ .

This is a consequence of charge conservation and assumption that currents are steady, that is no charge piles up at the junction.

### Kirchhoff's Second Rule:

The algebraic sum of changes in potential around any closed resistor loop must be zero. This is based on the principle that electrostatic forces alone cannot do any work in a closed loop, since this work = Potential difference, which is zero, if we start at one point of the loop and come back to it.



Applied to a loop as above (which could be part of a bigger circuit). This gives:

$$(R_1 + R_2) I_1 + R_3 I_3 + R_4 I_4 = 0$$

11. Points to remember in case of current loops:

(i) Choose any closed loop in the network and designate a direction (in this example counter clockwise) to traverse the loop.

(ii) Go around the loop in the designated direction, adding emf's and potential differences. An emf is counted as **positive** when it is traversed (-) to (+) { $\epsilon$  in the above examples} and **negative** in the opposite case i.e., from (+) to (-). {in the above example}

An IR term is counted negative if the resistor is traversed in the same direction of the assumed current, and positive if in the opposite direction.

(iii) Equate the total sum to zero.

12. The Wheatstone bridge is an arrangement of four resistances –  $R_1, R_2, R_3, R_4$ , as shown in the text. The null point condition is given by

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

This is also known as the balance condition. If  $R_1, R_2, R_3$  are known, for instance,  $R_4$  can be determined.

$$R_4 = \left( \frac{R_2}{R_1} \right) R_3$$

13. In a balanced condition of the meter bridge,

$$\frac{R}{S} = \frac{P}{Q} = \frac{\sigma \ell_1}{\sigma(100 - \ell_1)} = \frac{\ell_1}{100 - \ell_1}$$

$$\therefore R = \frac{S \ell_1}{(100 - \ell_1)}$$

$\sigma$  : Resistance per unit length of wire

$\ell_1$ : Length of wire from one end where null point is obtained.

14. The potentiometer is a device to compare potential differences. Since the method involves a condition of no current flow, the device can be used to measure potential differences; internal resistance of a cell and compare emf's of two sources.

The potential gradient of the wire in a potentiometer depends on the current in the wire.

If an emf  $\epsilon_1$  is balanced against length  $\ell_1$ ,

$$\epsilon_1 = \rho \ell_1$$

Similarly, if  $\epsilon_2$  is balanced against  $\ell_2$ ,

$\epsilon_2 = \rho \ell_2$ , then the comparison of emf's of the two cells is given by

$$\therefore \frac{\epsilon_1}{\epsilon_2} = \frac{l_1}{l_2}$$

### **Top Formulae**

1. Electrical conductivity is the inverse of specific resistance for a conductor

whereas the specific resistance is the resistance of unit cube of the material of the conductor.

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

$\sigma$  = conductivity

$\rho$  = resistivity

SI unit of conductivity =  $\text{mhm}^{-1}$

2. Mobility  $\mu$  is defined to be the magnitude of drift velocity per unit electric field.

$$\mu = \left( \frac{v_d}{E} \right)$$

Now,  $v_d = \frac{q\tau E}{m_q}$  where  $q$  is the electric charge of the current carrier and

$m_q$  is its mass.

$$\therefore \mu = \left( \frac{q\tau}{m_q} \right)$$

Mobility is a measure of response of a charge carrier to a given external electric field. If the mass of a charge carrier is large, then for

a given field  $\vec{E}$ , its acceleration will be small and will contribute very little to the electric current.

3. **Ohm's law**  $R = \frac{L}{\sigma A}$

where R is called resistance of the material.

4. Resistivity  $\rho$  is defined to be reciprocal of conductivity

$$\rho = \frac{1}{\sigma}$$

It is measured in ohm-metre ( $\Omega \text{ m}$ ).

5. Resistivity as a function of temperature is given as,

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

$\alpha$  : Temperature coefficient of resistivity.  $\rho_0$  is the resistivity of the material at some initial reference temperature.  $\rho_T$  is the resistivity of the material at temperature T. At low temperatures, its variation is non-linear.

6. (a) Total resistance R of n resistors connected in series is given by

$$R = R_1 + R_2 + \dots + R_n$$

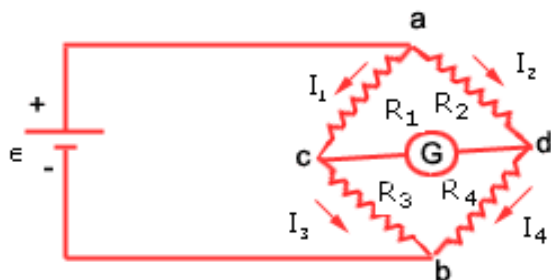
(b) Total resistance R of n resistors connected in parallel is given by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n}$$

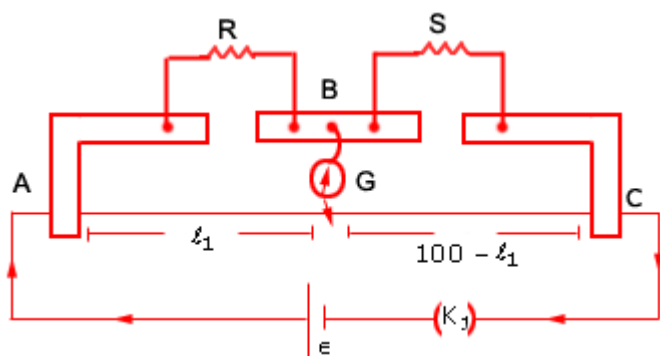


## Top Diagrams

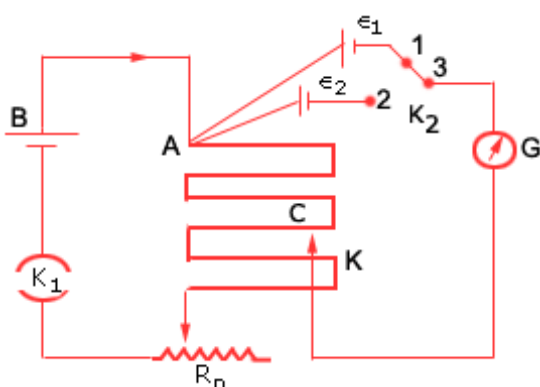
### 1. Balanced Wheatstone bridge



### 2. Balanced meter bridge



### 3. Potentiometer: Comparison of emf's of two cells:



## 4. Potentiometer: Determination of internal resistance of cell:

