CURRENT ELECTRICITY 13

CONTENTS

13.1 ELECTRIC CURRENT:

Definition:

The rate of flow of electric charge through the cross-section of a conductor is called electric current.

Mathematical Form:

If "q" charges pass through the cross-section of a conductor in time "t", then the electric current "I" is given by:

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

Unit:

S.I. unit of electric current is coul/sec which is called Ampere (Amp).

Definition of ampere:

If a charge of one coulomb passes through a conductor in one second, then the current passing through conductor is said to be one ampere.

$$1\ \text{Ampere} = \frac{1\ \text{Coulomb}}{1\ \text{Second}} = \text{coulomb/second.}$$

13.2 DIRECTION OF ELECTRIC CURRENT:

The electric current in a conductor is caused by the flow of electrons from the negative terminal to the positive terminal or from the lower potential to higher potential point. This current is called ***electronic current.*** Electronic current which is due to the flow of negative charges can be expressed in terms of an equivalent current due to the flow of positive charges in opposite direction called as ***conventional current***, as it retains the old belief about the direction of current from higher Potential to lower Potential.

13.3 OHM'S LAW:

Introduction:

A German Scientist Geore Simon ohm studied the relationship between voltage, current and resistance on the basis of his experimental results, he proposed a law which is known as ohm's law.

Statement: ***The current passing through a conductor is directly proportional to the potential difference applied across the terminals of the conductor, provided the temperature and other physical conditions of the conductor does not change.***

Explanation: If the Potential difference applied across the terminals of conductor is V and as a result current I flows through it, then mathematically:

$$I \propto V$$

$$I = KV$$

Where "K" is the constant known as the ***conductance*** of the material of conductor.

$$KV = I$$

$$V = I \times \frac{I}{K}$$

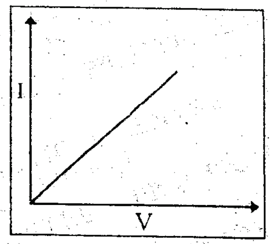
Where the reciprocal of conductance determines another physical property of conductor, called as the ***resistance*** of conductor, denoted by "R".

$$\frac{I}{K} = R$$

$\therefore \quad V = IR \quad$ where "R" is the resistance of conductor.

Graphical Representation:

The linear relationship exist between current and voltage whose graph is a straight line.



Limitation of Ohm's Law:

i) Ohm's law is applicable when Resistance and Physical conditions of conductor remains constant or when resistance of conductor remains constant.

ii) Ohm's law is applicable only for metallic conductors.

iii) Ohm's law valid at constant temperature.

Resistance:

The property of conductor which opposes the flow of charges is called Resistance, denoted by "R" or "r".

OR

It may be defined as "The ratio of the potential difference between the end of a conductor to the current flowing in the conductor is constant."

Unit:

S.I unit of resistance is volt/amp which is called ohm (Ω)

Definition of OHM:

If one- Ampere current is passing through the conductor due to one volt of potential difference across its terminal then resistance of conductor is said to be ohm (Ω).

$$\therefore \quad 1\Omega = \frac{1\text{ volt}}{1\text{ ampere}}$$

13.4 DEPENDENCE OF RESISTANCE UPON RESISTIVITY:

OR

DEPENDENCE OF RESISTANCE UPON PHYSICAL DIMENSIONS OR CONDITIONS OF CONDUCTOR

The resistance of a conductor is due to the collision of free electrons with the atoms. It has been found experimentally that at constant temperature, the resistance of conductor depends upon the following factors.

(1) Length of the conductor.
(2) Cross-sectional area of the conductor.
(3) Material of the conductor.
(i) Directly upon the length of the conductor.

$$R \propto L \longrightarrow (1)$$

(ii) Inversely upon the cross sectional area of conductor

$$R \propto \frac{1}{A} \longrightarrow (2)$$

From (1) & (2):

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

$$OR \quad R = (\text{constant}) \frac{L}{A}$$

$$OR \quad R = \frac{\rho L}{A}$$

Where ρ is the constant, known as the ***resistivity*** or ***specific resistance*** of the material of conductor.

Unit:

S. I unit of resistivity is ohm meter (Ωm).

Definition of Resistivity:

The resistivity of a material of conductor is the resistance of its unit area of cross section and per unit of its length.

13.5 DEPENDENCE OF RESISTANCE UPON TEMPERATURE:

The resistance of a conductor is due to the collision of free electrons with the atoms. When the temperature of a conductor rises, the amplitude of vibration of atoms also increases which increases the probability of collision of free electrons with them. It reduces the drift velocity of free electrons and hence increases electrical resistance of circuit.

Expression:

Let us suppose that resistance of a conductor at "0°C" is "R_o" and at a higher temperature "T" is "R_T". If the change in resistance is $\Delta R = R_T - R_o$, depends upon the following two factors.

(i) Original resistance R_o (ii) Difference is temperature ΔT

$$\Delta R \propto R_o \Delta T$$

$$\Delta R = \alpha R_o \Delta T \quad \text{.........(1)}$$

$$R_T - R_o = \alpha R_o \Delta T$$

$$R_T = R_o + \alpha R_o \Delta T$$

$$R_T = R_o \{1 + \alpha \Delta T\}$$

Where α is the constant of proportionality called as *co-efficient of temperature.*

Co-efficient of temperature:

Definition:

If may be defined as "The fractional charge in resistance due to per Kelvin rise in temperature.", denoted by "α" $\boxed{\alpha = \frac{\Delta R}{Ro\Delta T}}$

Unit:

Its S. I unit is K^{-1} or $°C^{-1}$.

13.6 RELATION BETWEEN TEMPERATURE CO-EFFICIENT AND RESISTIVITY:

Experimentally it has been found that resistance of conductor depends directly upon the initial resistance (Resistance at O °C), rise in temperature of conductor and co-officient of temperature of material of conductor, mathematically.

$$\Delta R = \alpha R_0 \Delta T$$

$$\alpha = \frac{\Delta R}{R_0 \Delta T}$$

$$\alpha = \frac{R_T - R_0}{R_0 \Delta T}$$

Since resistivity is directly proportional to the resistance of a metal, therefore,

$$\alpha = \frac{\rho_T L/A - \rho_0 L/A}{\rho_0 L/A \ \Delta T}$$

$$\alpha = \frac{L/A\,(\rho_T - \rho_0)}{L/A\ \rho_0 \Delta T}$$

$$\alpha = \frac{\rho_T - \rho_0}{\rho_0 \Delta T}$$

Where ρ_T and ρ_o are the resistivities of the material at T °C and 0°C

13.7 POWER DISSIPATION IN RESISTORS:

Definition:

When current flows in a conductor then a part of electrical energy appears in the form of heat energy which is known as power dissipation in conductor.

Explanation:

Suppose q charge flows through a conductor of resistance R in time t seconds when a potential difference V is maintained across its ends so that the current flowing through the conductor, I = q/t. As the charge flows through the conductor they dissipate energy in it. The energy dissipated is equal to the potential energy lost by the charge as they moves through the potential difference that exists between the two ends of the conductor. This energy is delivered to the atoms, hence increase their vibrational energy. As the energy dissipated in the conductor in the time t is qV. Thus the power dissipated as heat due to electric current is,

$$\text{Power} = \frac{qV}{t}$$

OR $\quad P = VI \quad \left[\because \frac{q}{t} = I\right]$ ---------------- (1)

From ohm's law $\quad V = IR$

Equation (1)=> $\quad P = (IR)I$

$P = I^2R$ ---------------- (2)

OR $\quad I = V/R$

Equation (1)=> $\quad P = V(V/R)$

$P = V^2/R$ ---------------- (2)

Unit: The S.I unit of power is watt.

Watt: When one Joule of energy is dissipated in one second is called one watt power.

$$\text{Watt} = \frac{\text{Joule}}{\text{Second}}$$

13.8 ENERGY IN KILOWATT HOUR:

Kilo watt hour is the unit of electrical energy. One kilo watt hour (Kwh) is defined as:

If a power of one Kilowatt is maintained for one hour then the energy generated by electrical current is said to be one Kilo watt hour.

$$\text{Energy in Kwh} = \frac{\text{Power in watt} \times \text{time in hour}}{1000}$$

$$1\ \text{Kwh} = 1\ \text{Kw} \times 1\ \text{hour}$$

$$1\ \text{Kwh} = 1000\ \text{watt} \times 3600\ \text{sec.}$$

$$1\ \text{Kwh} = 36 \times 10^5\ \text{J.} = 3.6 \times 10^6\ \text{J}$$

13.9 ELECTROMOTIVE FORCE (E.M.F):

The e.m.f (E) of the source is defined as the energy supplied to unit charge or e.m.f. of the source is the work done on unit charge.

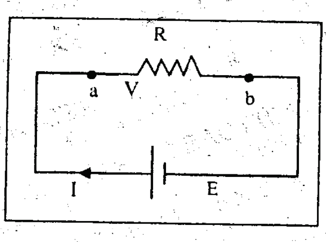
A cell or a battery is called as a source as it maintains steady current across the resistance. The energy supplied by the cell to the charge carriers is derived from the conversion of chemical energy into electrical energy inside the cell. Like other components in a circuit a cell also offers some resistance which is due to electrolyte present in the cell. This resistance is called internal resistance "r" of the cell. The role of a cell or a battery could be varied in electrical circuits depending upon the fact that weather it is used in circuit as a source or a load or simply an e.m.f.

(i) CELL OR BATTERY AS A SOURCE (CELL OR BATTERY IS CONNECTED WITH EXTERNAL RESISTANCE):

Let us consider a load or an external resistance R is connected across a cell of e.m.f E. As cell maintains steady current I in the circuit, therefore, it will behave like a source.

Due to presence of internal resistance 'r' of cell, the total resistance of circuit would be (R + r). From ohm's law, the current I flowing through the circuit is given by

$$I = \frac{E}{R+r}$$



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

$$E = IR + Ir$$

Where Ir is the loss of voltage and IR is the voltage across the terminals of load, called as ***Terminal voltage***, therefore.

$$\boxed{E = V + Ir}$$

(ii) CELL OR BATTERY AS AN E.M.F (CELL OR BATTERY NOT CONNECTED WITH EXTERNAL RESISTANCE):

If cell or battery is not connected across the external resistance i.e. the terminals of a cell or battery are shot directly then cell or battery in their own capacity behaves like a load and there would be no internal resistance of the source, hence there would be no loss of voltage in the circuit, therefore, from ohm's law, the current flowing through the circuit is given by:

$$I=\frac{E}{R}$$

$$E = IR$$

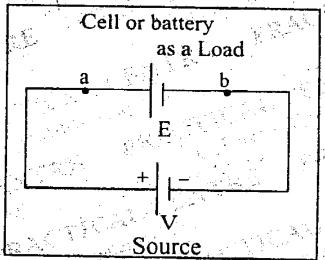
OR $$\boxed{E = V}$$

In other words if internal resistance of circuit is ignored then e.m.f of cell is equal to its terminal voltage.

(iii) CELL OR BATTERY AS AN EXTERNAL LOAD:

Let us consider a cell or a battery connected in an electrical circuit as an external load of resistance R with a source of voltage V which maintains the steady current I in the circuit.

Due to presence of internal resistance 'r' of a cell or a battery, the total resistance of the circuit would be (R +r). From ohm's law, the current I flowing through the circuit is given by:



$$I=\frac{V}{R+r}$$

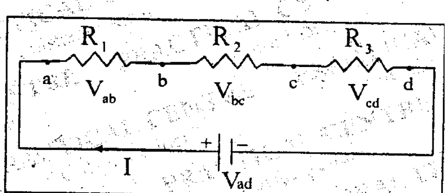
$$V = I(R + r)$$

$$V = IR + Ir$$

Where Ir is the loss of voltage and IR is the voltage across the terminals of load which is the e.m.f of cell or battery, therefore,

OR $$\boxed{V = E + Ir}$$

13.10 RESISTANCES IN SERIES:



Resistances are said to be joined in series when they offer only one path for the flow of electric current. It means that in series combination same current passes through each resistor and the sum of all potential drops across each resistor is equal to the total potential drop across the circuit.

$$V_{ad} = V_{ab} + V_{bc} + V_{cd}$$

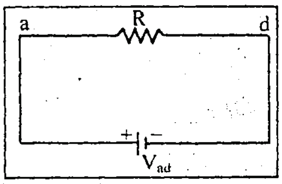
If R is the equivalent resistance of R_1, R_2 and R_3 then it will give the equal potential drop V_{ad} when current I will flow through it. By applying ohm's law V =IR, we get

$$V_{ad} = IR, \quad V_{ab} = IR_1, \quad V_{bc} = IR_2 \quad \text{and} \quad V_{cd} = IR_3$$

$$IR = IR_1 + IR_2 + IR_3$$

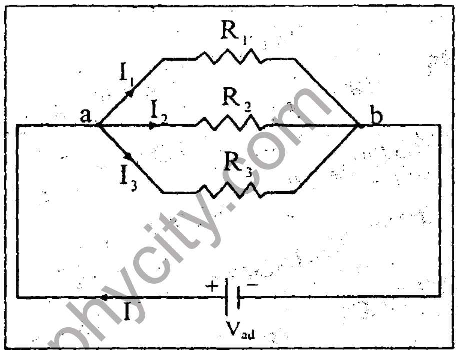
$$\cancel{I}R = \cancel{I}(R_1+R_2+R_3)$$

$$\boxed{R = R_1+R_2+R_3}$$



Thus in series combination, the equivalent resistance is the sum of all individual resistances. It means that the equivalent resistance in series combination increases.

13.11 RESISTANCES IN PARALLEL:



Resistances are said to be joined in parallel if they are connected in different paths, so that they provide several paths for the flow of electric current. It means that in parallel combination, same potential difference exists across each resistor and the sum of current through individual resistors is equal to the total current in the circuit.

$$I = I_1 + I_2 + I_3$$

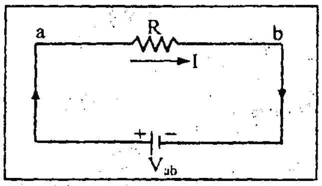
If R is the equivalent resistance of the combination of R_1, R_2 and R_3, then the current of each resistor can be obtained from ohm's law as:

$$I = \frac{V_{ab}}{R}, \quad I_1 = \frac{V_{ab}}{R_1}, \quad I_2 = \frac{V_{ab}}{R_2}, \quad I_3 = \frac{V_{ab}}{R_3},$$

$$\frac{V_{ab}}{R} = \frac{V_{ab}}{R_1} + \frac{V_{ab}}{R_2} + \frac{V_{ab}}{R_3}$$

$$\frac{\cancel{V}_{ab}}{R} = \cancel{V}_{ab}\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$



Thus in parallel combination, the reciprocal of equivalent resistance is the sum of reciprocals of individual's resistances. It means that the equivalent resistance in parallel combination decreases.