unit:-7 Current Electricity (1)

unit-7.1 : Electric current

Electric current :→ The electric current is defined as the rate of flow of charge through a conductor.

i.e. electric current $(I) = \frac{\text{charge}(q)}{\text{time}(t)}$

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

SI unit :→ $I = \frac{q}{t} = \frac{\text{coulomb}}{\text{sec}} = \text{Ampere}(A)$

One Ampere :→ The current is said to be one Ampere if one coulomb charge flows through a conductor in unit time.

Electric current is scalar quantity.

Types of electric current :→

1) Direct currect (D.C.) :→ The current whose magnitude and direction remains constant at all the time is called direct current.

Ex:- current from a battery.

2) Alternating current (A.C.) :→ The current whose magnitude and direction changes continuously ~~[illegible]~~ at all the time is ~~[illegible]~~ called alternating current.

Ex:- current from a.c. generator.

current density (J) :→ The current flowing through a conductor per unit area is called current density.

i.e. current density $(J) = \frac{I}{A}$

Drift velocity :→ The average velocity acquired by the free electrons in a material when it is subjected to an electric field is called drift velocity.

It is denoted by V_d.

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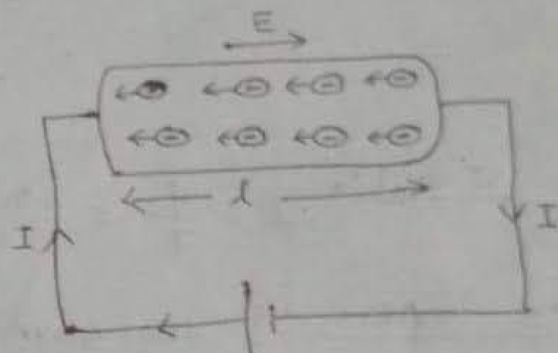
Relation between electric current and drift velocity :→

Suppose, a conductor of length l and cross-sectional area A as shown in fig. Let, n be the number of free electrons per unit volume and e is the charge on each electron.



Then,

volume of conductor = Al

Total no. of electrons = nAl

$\therefore$ Total charge (q) = $nAle$

Now, when a battery is joined across the conductor then current (I) flows through it in a time t as shown in fig.

we know that,

$$\text{Electric current } (I) = \frac{q}{t}$$

$$= \frac{nAle}{t}$$

$$\therefore \boxed{I = nAV_d e} \quad \text{——— (1)}$$

where, $V_d = \frac{l}{t}$; is drift velocity.

This is the relation between current & drift velocity

Again, we know that,

$$\text{current density } (J) = \frac{I}{A}$$

$$= \frac{nAv_d e}{A}$$

$$\therefore \boxed{J = nv_d e} \quad \text{———— (2)}$$

Imp/ **Ohm's law :→** It states that "under constant physical conditions, the current flowing through a conductor is directly proportional to the potential difference across its ends".

If I is the current flowing through a conductor and V is potential difference across it,

Then, $V \propto I$

$$\therefore \boxed{V = RI}$$

where, R is the proportionality constant known as resistance of conductor.

Resistance (R) :→ The resistance of a conductor is defined as its ability to oppose the flow of charge through the conductor.

It is denoted by R.

In electrical circuit, the resistance is symbolized as

 or, 

unit of R :→ we have,

$$V = IR$$

$$\therefore R = \frac{V}{I} = \frac{\text{Volt}}{\text{Ampere}} = \text{ohm} (\Omega).$$

Resistivity or specific resistance (ρ):→

Experimentally, it is found that the resistance of a conductor is,

1) directly proportional to its length,

i.e. $R \propto l$ ——— (1)

& (ii) inversly proportional to its cross-sectional area,

i.e. $R \propto \frac{1}{A}$ ——— (2)

combining eqⁿs (1) & (2), we get,

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

$$\therefore \boxed{R = \frac{\rho l}{A}} \quad \text{——— (3)}$$

where, ρ is the proportionality constant known as the resistivity whose value depends upon the material of the conductor.

If, $l = 1m$ & $A = 1\,m^2$ then from eqⁿ (3), we get,

$$\boxed{R = \rho} \quad \text{——— (4)}$$

Hence, the resistivity is defined as the resistance of conductor of unit length and unit cross-sectional area.

unit of resistivity :→ ohm-meter (Ωm)

Combination of resistors :-

The resistances are combined in an electrical circuit in two different ways.

1) Series combination
2) parallel combination

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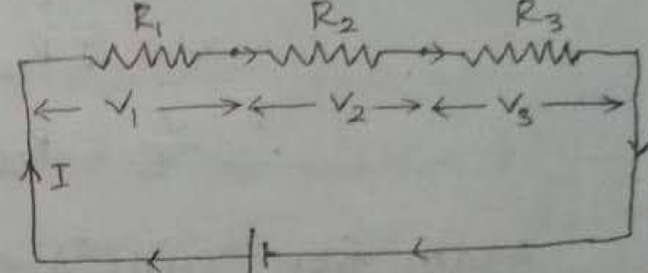
1) Series combination :-

"Resistances are said to be joined in series combination if they are joined end-to-end way so that same current flows through each of them."



Suppose, three resistors of resistances R_1, R_2 and R_3 are connected in series as shown in fig. When the combination is joined to a battery, the same current flows through each resistor but the potential difference is different across each restor.

Let, I is the current flowing through each resistor and V_1, V_2 & V_3 be the potential differences across R_1, R_2 & R_3 respectively.

Then, from ohm's law,

$$\left.\begin{aligned} V_1 &= IR_1 \\ V_2 &= IR_2 \\ V_3 &= IR_3 \end{aligned}\right\} \quad \text{——— (1)}$$

If V is the potential difference across combination, then,

$$V = V_1 + V_2 + V_3 \quad \text{——— (2)}$$

Now, from eqⁿˢ 1 & 2, we get,

$$V = IR_1 + IR_2 + IR_3$$

$$\therefore V = I(R_1 + R_2 + R_3)$$

$$\therefore \frac{V}{I} = R_1 + R_2 + R_3 \quad \text{———} \quad (3)$$

Let, R_s is the equivalent resistance of the combination then,

$$V = IR_s$$

$$\therefore \frac{V}{I} = R_s \quad \text{———} \quad (4)$$

Again, from eqⁿˢ 3 & 4, we get,

$$\boxed{R_s = R_1 + R_2 + R_3} \quad \text{———} \quad (5)$$

Hence, the equivalent resistance is equal to the sum of individual resistances.

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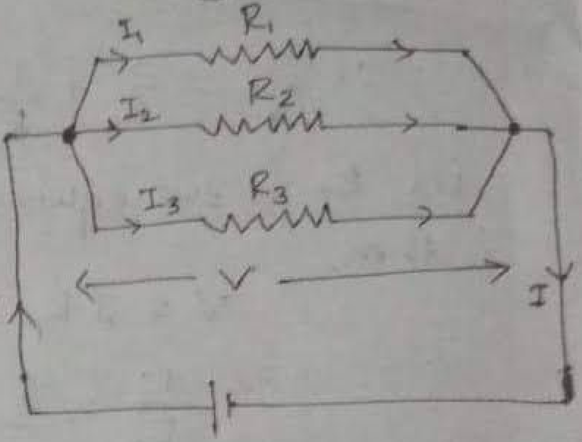
2) <u>parallel combination</u> :⇒ "Resistances are said to be connected in parallel if one ends of each resistors are joined to one common point and other ends are joined to another common point so that the potential difference across each resistors is same."



Suppose, three resistances R_1, R_2 and R_3 are connected in parallel as shown in fig. When the combination is joined to a battery then the potential difference across each resistor is same but the current through each resistor are different.

Let; I_1, I_2 and I_3 are the currents through R_1, R_2 and R_3 respectively and v is the potential difference across the combination then,

From ohm's law,

$$\left.\begin{aligned} I_1 &= \frac{V}{R_1} \\ I_2 &= \frac{V}{R_2} \\ I_3 &= \frac{V}{R_3} \end{aligned}\right\} \text{———} (1)$$

If I is the total current in the circuit then,

$$I = I_1 + I_2 + I_3 \quad \text{———} (2)$$

Now, from eqns. (1) & (2), we get,

$$I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\therefore I = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

$$\therefore \frac{I}{V} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad \text{--- (3)}$$

Let, R_p is the equivalent resistance of the combination, then,

$$V = IR_p$$

$$\therefore \frac{1}{R_p} = \frac{I}{V} \quad \text{--- (4)}$$

Again, from eqns. (3) & (4), we get,

$$\therefore \boxed{\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} \quad \text{--- (5)}$$

Hence, the reciprocal of equivalent resistance is equal to the sum of reciprocals of individual resistances.

<u>Galvanometer (G)</u> :→ It is an instrument used to detect the current in an electrical circuit.

In electrical circuit, galvanometer is symbolized as

-(G)- or -(G)-

<u>shunt (S)</u> :→ The small resistance connected in parallel with a galvanometer is known as shunt.

It is denoted by S.

Imp <u>Conversion of galvanometer into an ammeter</u> :→

Ammeter is a device used to measure the current flowing in a circuit.

Such an instrument can be constructed by joining shunt in parallel with galvanometer as shown in fig. Let,

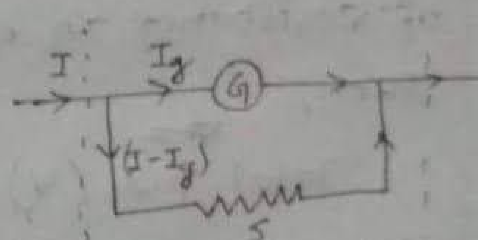


fig: Ammeter

G is the resistance of galvanometer and I_g and $(I-I_g)$ are the currents through galvanometer and shunt respectively.

Then,

p.d. across G = p.d. across S

$$\therefore \; I_g G = (I - I_g) S$$

$$\therefore \; \boxed{S = \frac{I_g G}{I - I_g}} \quad \text{——— (1)}$$

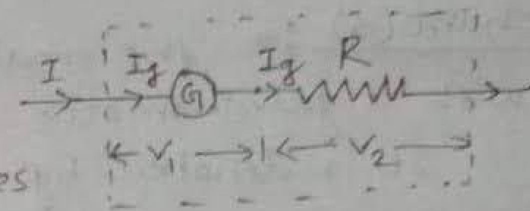
This is the value of shunt connected in parallel to galvanometer to convert it into ammeter. //

Imp

conversion of galvanometer into voltmeter :→

A voltmeter is a device used to measure the potential difference between two points in an electrical circuit.

Such an instrument can be constructed by joining a very high resistance in series with galvanometer as shown in fig.



Let, I_g is the current through galvanometer of resistance G and R is the very high resistance.

Then,

$$\text{Total p.d. } (V) = V_1 + V_2$$

$$V = I_g G + I_g R$$

$$\therefore V - I_g G = I_g R$$

$$\therefore \boxed{R = \frac{V - I_g G}{I_g}} \quad \text{——— (1)}$$

This is the value of high resistance joined in series with galvanometer convert it into voltmeter.

short questions:-

1) What is the ratio of maximum to minimum resistance obtained from two wires each of resistance R ?

=)

when the wires are joined in series then,

$\cancel{R_{max} = \frac{R \cdot R}{R+R}}$

$\cancel{R_{series} = \frac{R_1 R_2}{R_1+R_2}}$

$\therefore R_{max} = R + R \qquad (\because R_s = R_1 + R_2)$

$\therefore R_{max} = 2R$ ——— ①

Again, when the wires are joined in parallel then,

$\therefore R_{min} = \frac{R \cdot R}{R+R} \qquad \left(\because R_p = \frac{R_1 R_2}{R_1 + R_2}\right)$

$\therefore R_{min} = \frac{R^2}{2R}$ ——— ②

Then,

$$\frac{R_{max}}{R_{min}} = \frac{2R}{\frac{R^2}{2R}}$$

$$= \frac{2R}{1} \times \frac{2R}{R^2}$$

$$= 4$$

$\therefore R_{max} : R_{min} = 4:1$

Imp Q) A wire is stretched to double its length. what happens to its resistance and resistivity ?

⇒ we know that,

$$R = \frac{\rho l}{A} \quad ; \text{where, } R = \text{resistance},\ l = \text{length},\ \rho = \text{resistivity}$$

$$\therefore R = \frac{\rho l^2}{Al}$$

$$\therefore R = \frac{\rho l^2}{V} \quad \text{——— (1)} \quad (\because \text{Volume}(V) = Al)$$

Now, the wire is stretched to double its length then,

$$\text{New resistance } (R') = \frac{\rho (2l)^2}{V} \quad \left(\because \begin{array}{l}\rho = \text{constant} \\ V = \text{constant}\end{array}\right)$$

$$\therefore R' = \frac{4\rho l^2}{V} \quad \text{——— (2)}$$

Now, from eqns. (1) & (2), we get,

$$\boxed{R' = 4R}$$

Hence, the resistance increases by four times but the resistivity remains constant because its value depends upon the material of the wire.

Imp Q) why is an ammeter always connected in series in an electrical circuit ?

Imp Q) why is a voltmeter always connected in parallel across the resistance in a circuit ?