UNIT 10 – CURRENT ELECTRICITY

Electric Current:

The quantity of charge flowing through a conductor per unit time is called 'electric current'. Or, electric current may also be defined as "the rate of flow of charge through a point in an electric circuit".

$$\text{Electric current (I)} = \frac{Quantity\ of\ Charge\ (Q)}{Time\ (t)}$$

SI Unit of Current: Coulomb/Second or Ampere

Definition of 1 ampere of current:

Current is said to 1 amp. when 1 coulomb of charge flows through a conductor for 1 second.

Ohm's law

Ohm's law may be stated as "the strength of current (I) flowing through a conductor is directly proportional to the potential difference or voltage (V) applied across the terminals of the conductor".

Mathematically,

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

Resistance (R):

It is the property of the material of a conductor by virtue of which it opposes the flow of electric current through an electric circuit.

Unit of Resistance: Ohm or Ω

Dependence of Resistance:

The resistance of a conductor depends upon the following factors:

i. Length (l) of the conductor.

ii. Area of cross section (a) of the conductor.

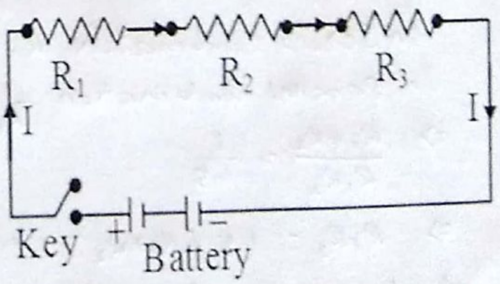
iii. Nature of the material of the conductor.

iv. Temperature.

Series combination of resistors

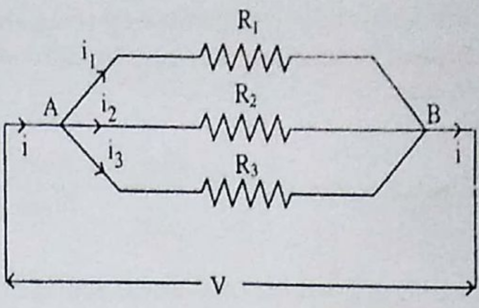
If R_1, R_2 and R_3 are three resistors connected in series, then, Effective/Combined/ total/Equivalent resistance in series combination

$R_S = R_1 + R_2 + R_3$



Parallel combination of resistors

If R_1, R_2 and R_3 are three resistors connected in parallel then, Effective/Combined/ total/Equivalent resistance in series combination



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

PROBLEM – 1

Calculate the potential difference to be applied across a conductor of resistance 16 Ω so that a current of 15 amperes may flow through it.

Sol^n: Given data: $R = 16\,\Omega$

$I = 15$ Amp. $V = ?$

Applying ohm's law

$I = \frac{V}{R} \Rightarrow V = I \times R = 15 \times 16 = 240$ Volt. (Ans)

PROBLEM – 2

Determine the current flowing through the filament of a lamp having a constant resistance of 440 Ω and connected across 220 V mains.

Sol^n: Given data: $R = 440\,\Omega$, $V = 220$ Volt., $I = ?$

Applying ohm's law

$I = \frac{V}{R} = \frac{220}{440} = \frac{1}{2} = 0.5$ amp. (Ans)

PROBLEM – 3

The equivalent resistance of two resistors R_1 & R_2 connected in series is 8 Ohm and is 1.5 Ohm when connected in parallel. Find the resistances of the two resistors.

Sol^n: Given data:

In Series Combination $R_1 + R_2 = 8\,\Omega$ ---- (1)

In Parallel Combination $\frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{1.5}$

$\Rightarrow \frac{R_1 + R_2}{R_1 R_2} = \frac{1}{1.5}$

$\Rightarrow R_1 R_2 = 1.5(R_1 + R_2) = 1.5 \times 8 = 12$

Applying the formula

$(R_1 - R_2)^2 = (R_1 + R_2)^2 - 4R_1R_2$

$= 8^2 - 4 \times 12$

$= 64 - 48 = 16$

$\Rightarrow R_1 - R_2 = \sqrt{16} = 4$ ---- (2)

Now, from eq^n (1) & eq^n (2)

$(R_1 + R_2) + (R_1 - R_2) = 8 + 4 = 12$

$\Rightarrow 2R_1 = 12$

$\Rightarrow \boxed{R_1 = 6}$

Now,

$R_1 + R_2 = 8$

$\therefore 6 + R_2 = 8$

$\Rightarrow R_2 = 8 - 6$

$\Rightarrow \boxed{R_2 = 2}$

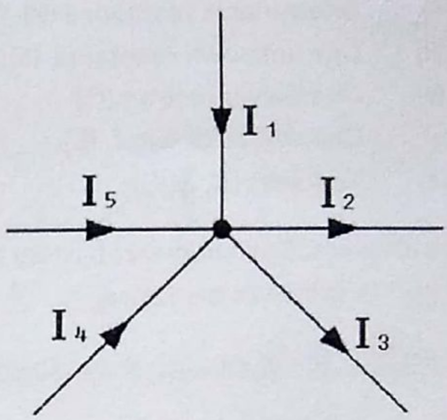
Kirchhoff's laws

Kirchhoff's Current laws (KCL):

"The algebraic sum of the currents meeting at a point (junction) is zero".

Mathematically,

$$\sum_{i=1}^{i=n} i_n = 0$$



Let us consider five resistors with resistances I_1, I_2, I_3, I_4 and I_5 meet at a junction 'O'.

As per sign convention, current is given a +ve sign if it enters into a junction and is given a – ve sign if it leaves a junction.

Applying KCL to the network of circuit given in the figure,

$$\sum_{i=1}^{i=n} i_n = 0$$

or, $I_1 - I_2 - I_3 + I_4 + I_5 = 0$

Kirchhoff's Voltage laws (KVL):

"In a closed electric circuit the algebraic sum of e.m.f. is equal to the algebraic sum of the products of currents and resistances acting at various arms of the closed loop of circuit.

$$\sum_{i=1}^{i=n} i_n \times r_n = \sum_{i=1}^{n} E_n$$

Sign conventions:

(i) **If the direction of current is clockwise, then it is given a +ve sign (i = +ve)**

(ii) **If the direction of current is anti-clockwise, then it is given a – ve sign(i = - ve)**

(iii) **If current leave + ve terminal of the battery, then e.m.f is given a + ve sign (E = +ve)**

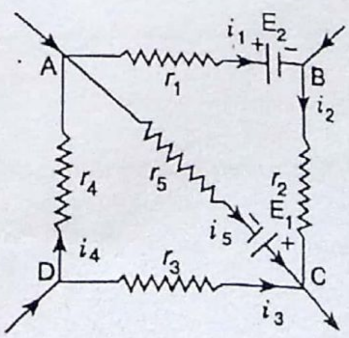
(iv) **If current leave - ve terminal of the battery, then e.m.f is given a – ve sign (E = – ve)**

Applying KVL in the mesh ABC, we have

$i_1r_1 + i_2r_2 - i_5r_5 = E_1 - E_2$

Applying KVL in the mesh ACD, we have

$-i_3r_3 + i_4r_4 + i_5r_5 = E_1$

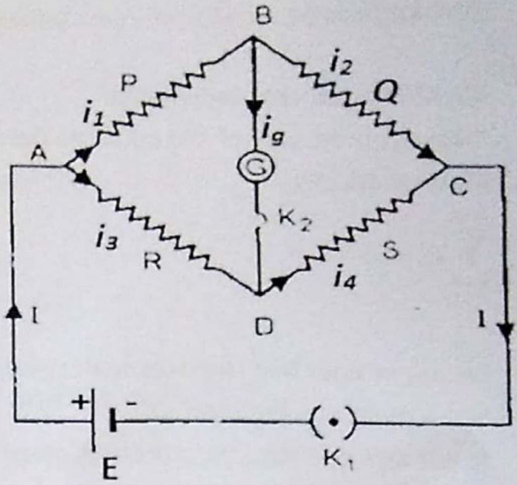


Application of Kirchhoff's laws to Wheatstone Bridge

A Wheatstone bridge is an electrical arrangement consisting of the following parts:

(i) Two known resistances (P & Q)
(ii) One variable resistance (R)
(iii) One unknown resistance (S)
(iv) One Galvanometer (G)
(v) One source of e.m.f. (E)
(vi) Two keys (K_1 & K_2)

The resistances, Galvanometer battery and the keys are arranged as shown in the figure.



(Wheastone Bridge)

Applying KCL at the junction B and D, we have:

At the junction 'B': $i_1 - i_g - i_3 = 0$ --------------- (i)

At the junction 'D': $i_2 + i_g - i_4 = 0$ -----------------(ii)

Applying KVL in the mesh ABD, we have:

$i_1P + i_gG - i_3R = 0$ -----------------------------------(iv)

Applying KVL in the mesh BCD, we have:

$i_2Q - i_gG - i_4S = 0$ -----------------------------------(v)

If we reduce the resistance of the variable arm AD (R), then the current in the arms AB, BC & BD will decrease. Now, the variable resistance 'R' is so adjusted that, the flow of current flowing through the galvanometer becomes zero. This condition is called balanced condition or null deflection condition. Under balanced condition, $i_g = 0$ and the equations (i) to (v) respectively become:

$i_1 = i_3$ -------------------------(vi)
$i_2 = i_4$ --------------------------(vii)
$i_1P = i_3R$ ------------------------------------(viii)
$i_2Q = i_4S$ -----------------------------------(ix)
Since, $i_1 = i_3$ and $i_2 = i_4$, equations (viii) & (ix) become

P = Q ------------------------------------ (x)

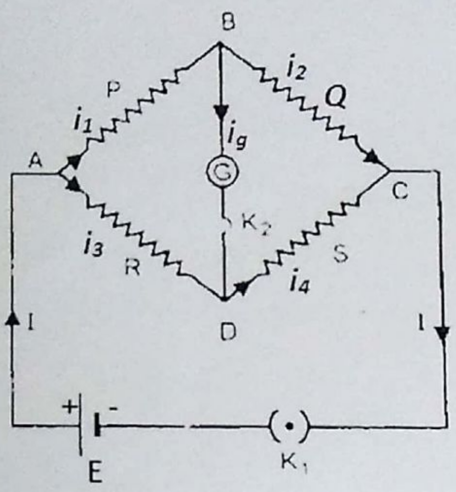
R = S --------------------------------------(xi)

Dividing equation (x) by equation (xi) we get,

$$\frac{P}{Q} = \frac{R}{S} \quad \Rightarrow \quad Unknown\ Resistance\ (S) = \frac{Q \times R}{P}$$

Q. For the Wheatstone bridge circuit of the given figure, solve the following problems:

If P = 1 Ω, Q = 2 Ω, and R = 3 Ω, to what value should 'S' be adjusted so as to achieve a balanced condition?



Solution:

Given data:

P = 1 Ω

Q = 2 Ω

R = 3 Ω

S = ?

Under balanced condition,

$\frac{P}{Q} = \frac{R}{S}$ => $S = R \times \frac{Q}{P}$

$\Rightarrow S = 3 \times \frac{2}{1} = 6\,\Omega$

Hence, the value of 'S' should be adjusted to 6 Ω so as to achieve a balanced condition.