CHAPTER-12

ELECTRICITY

ELECTRIC CURRENT:

Electric current is expressed by the amount of charge flowing through a particular area in unit time. In other words, it is the rate of flow of electric charges.

NOTE: In an electric circuit the direction of electric current is taken as opposite to the direction of the flow of electrons, which are negative charges.

If a net charge **Q**, flows across any cross-section of a conductor in time **t**, then the current **I**, through the cross-section is

$$\mathrm{I(current)} = \frac{\mathrm{Q(charge)}}{\mathrm{t(time)}}$$

SI units

- Current (I) is ampere or A
- Charge (Q) is coulomb or C
- Time (t) is seconds or s

NOTE:

- One charge contains nearly 6×10^{18} electrons
- An electron possesses a negative charge of 1.6×10^{-19} C

- ***One ampere*** is constituted by the flow of one coulomb of charge per second,

  i.e. $\mathbf{1\ A = \frac{1\ C}{1\ s}}$

Small quantities of current are expressed,

- in milli ampere **(1 mA = $\mathbf{10^{-3}}$ A)**
- in microampere **(1 µA = $\mathbf{10^{-6}}$ A).**

➢ **Ammeter** is the instrument used to measure the rate of current flowing in the circuit.

➢ **Ammeter** is always connected in series because the ammeter is designed to offer very less resistance, whereas if it is connected in parallel it would cause short circuit and will damage the ammeter.

HOW CHARGES FLOW IN A WIRE OR IN ANY CONDUCTING MATERIAL?? THINK

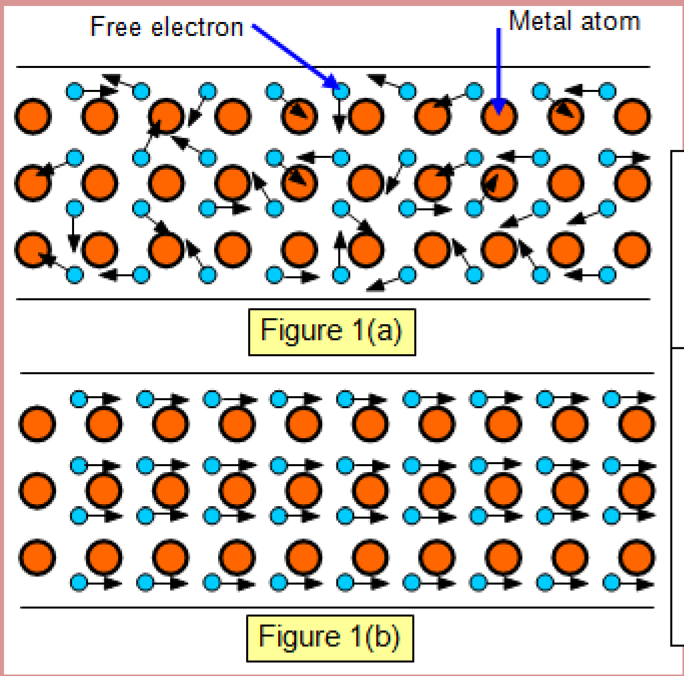


Figure 1(a)

Figure 1(b)

Figure 1(a) :

Before connecting the wire to a supply source (***battery***), the free electrons move randomly inside the wire. (Without any particular direction)

Figure 1(b) :

After connecting the wire to supply source, all these free electrons starts moving in one particular direction, i.e., towards the positive terminal of the supply source

(***i.e., battery***)

Problem #1:

The amount of charge that passes through the filament of a certain light bulb in 2 sec is 1.67 C.

a) What is the current in the light bulb?
b) What is the number of electrons that pass through the filament in one second?

Solution:

a) $I = \frac{Q}{t} = \frac{1.67}{2} = 0.835 \text{ A}$

b) As per the above problem,

1.67 C of charge passes ⟶ in 2 sec
_ ?_ _ C of charge passes ⟶ in 1 sec ⇒ $\frac{1 \times 1.67}{2} = 0.835 \text{ C}$

W.K.T, $1e^{-} = 1.67 \times 10^{-19} \text{ C}$

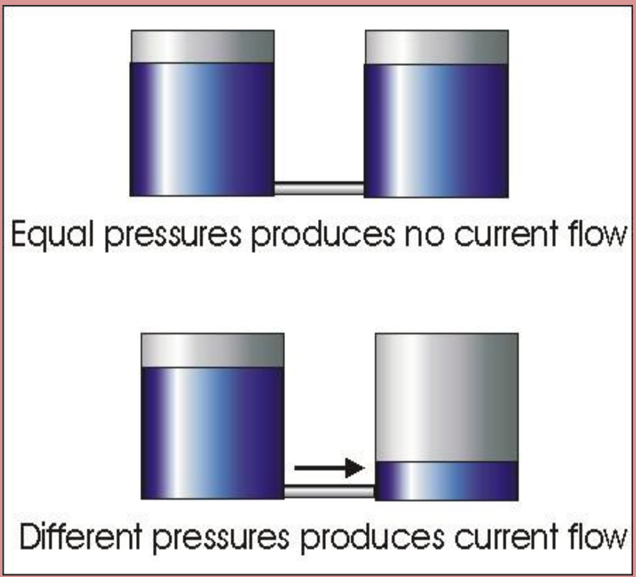
$$\therefore 0.867 \text{ C} \times \frac{1\, e^{-}}{1.6 \times 10^{-19} \text{ C}} = 5.22 \times 10^{18} \text{ electrons}$$

QUESTIONS:

1. 1×10^{20} electrons flow through a conductor in 3s.
   a) What is the charge flowing through the conductor?
   b) What is the current in the circuit?
   Ans: (a) 16 C

2. How many electrons pass a point in 5s if a constant current of 8 A is maintained in a conductor?

What makes the free electrons to flow in a wire?



THINK ABOUT IT !!!

In case of water pressure, the fully filled water tank starts flowing towards the empty tank due to the difference offered by the pressure.

And the water continuous to flow until the both tanks reaches the he equilibrium position.

Similarly the free electrons present in the wire or any conducting material do not flow by themselves.

The electrons move only if there is a difference offered by the electric pressure called POTENTIAL DIFFERENCE.

The difference of potential may be produced by the battery and when it's connected to the wire or the conducting material, the potential difference sets the charges (**e^-**) to move in the conductor and electric current is generated.

Basically battery or the potential difference sets the charges to move from one point to another.

Electric potential difference is defined as, the amount of work done to move a unit charge from one point to another point.

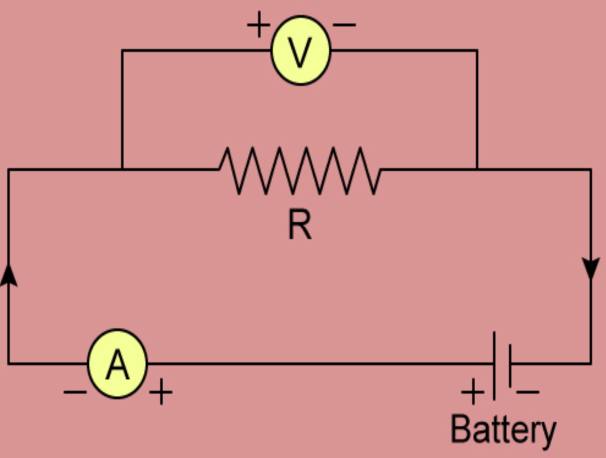
The potential difference is measured using the device –Voltmeter

Potential difference

$$(V) = \frac{work\ done\ (W)}{charge\ (Q)}$$

SI units:

- Potential difference(V) is volt or V
- Work done (W) is joule or J
- Charge (C) is coulomb or C



From the above figure

i. Voltmeter
ii. Resistor
iii. Ammeter
iv. Battery

Problem #2

The amount of work done by the source to move a charge of 2 C is 24 J. Find the potential difference of the source.

Solution:

Given: work done (W) = 24 J ; charge(Q) = 2 C ; V= ?

$$V = \frac{W}{Q} = \frac{24}{2} = 12\ V$$

QUESTIONS:

1. Calculate the work done if a charge of 5 C moving across two point having potential difference equal to 15 V. ***Ans: 75 J***
2. Calculate the potential difference between two points, if 1500 J of work done to carry a charge of 50 C from one point to other? ***Ans: 30 V***
3. How much energy is given to one coulomb of charge passing through a 10 V battery?

When one joule of work is done to move one coulomb of charge from one point to another is called ***one volt***

$$1\ V = \frac{1\ J}{1\ C}\ OR\ JC^{-1}$$

OHM'S LAW:

"The potential difference, V, across the ends of a given metallic wire in an electric circuit is directly proportional to the current flowing through it, provided its temperature remains the same."

Mathematically expressed as,

$$V \propto I$$

$$V = IR$$

Where R is the constant for the given metallic wire at a given temperature and is called its resistance.

Resistance is the property of the conductor (Eg: wire) that resist the flow of charges through it. The component having resistance is called **Resistor**.

SI unit of resistance is **ohm Or Ω**

NOTE:

According to Ohm's law we get,

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

From the above equation we can say that the current is inversely proportional to the resistance (R) and directly proportional to potential difference (V).

- If the resistance is doubled then the current gets halved. It means if you increase the resistance of the conducting material then the flow of charges will reduce and the flow current in that conducting material will be less.
- Rheostat is the device used to increase or decrease the resistance and it is named as variable resistance.

Resistance of the conductor depends on the following factors,

1. Depends on nature of the material
2. Depends on its area of cross section (thickness)
3. Depends on length of the material
4. Depends on temperature of the conductor

Based on the factors we get mathematical expression as,

$$\mathbf{R \;\alpha\; \frac{l}{A}} \quad \textbf{OR} \quad \mathbf{R = \rho \frac{l}{A}}$$

where ρ (rho) is the resistivity of the conducting material. SI unit of resistivity is Ωm

Problem #3

The resistance of metal wire of length 2 m is 26Ω. If the diameter of the wire is 40cm, what will be the resistivity of the metal?

Solution:

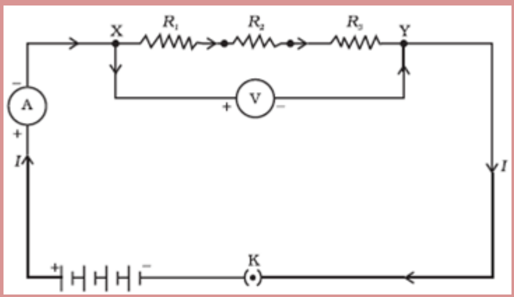
Given: l = 2m; R = 26Ω; d = 40cm = 0.4m; A = ?; ρ = ?

We know that area of cross section,

$$A = \pi r^2 = 3.14 \times (0.2)^2 = 0.1256\ m^2 \qquad \left\{\because r = \frac{d}{2}\right\}$$

$$R = \rho \frac{l}{A} \Longleftrightarrow \rho = \frac{RA}{l} = \frac{26 \times 0.1256}{2} = \mathbf{1.6328\ \Omega m}$$

Resistors connected in Series: (Series Combination)



When the resistors are connected in series, the current will be same but the voltage across the circuit will be different.

$$V = V_1 + V_2 + V_3 \text{ ----------- eq (1)}$$

Applying Ohm's law,

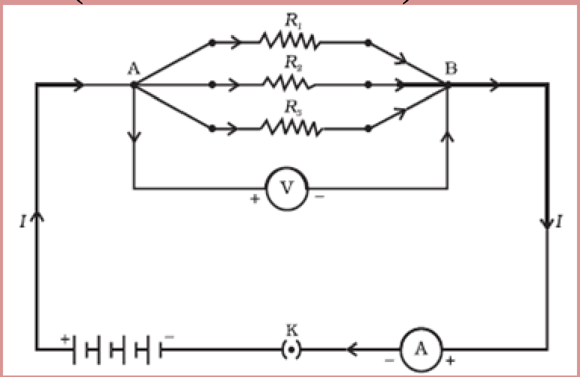
W.K.T $V = IR$; Then $V_1 = IR_1$; $V_2 = IR_2$; $V_3 = IR$

Substituting the above value in the equation (1),

$$V = V_1 + V_2 + V_3$$
$$IR = IR_1 + IR_2 + IR_3$$
$$IR = I(R_1 + R_2 + R_3)$$

$$\mathbf{R_s = R_1 + R_2 + R_3}$$

Resistors connected in Parallel: (Parallel Combination)



When the resistors are connected in parallel; the voltage will be different but the current across the circuit will be different.

$I = I_1 + I_2 + I_3$ ------------eq(1)

Applying Ohm's law,

W.K.T $I = \frac{V}{R}$; Then $I_1 = \frac{V}{R_1}$; $I_2 = \frac{V}{R_2}$; $I_3 = \frac{V}{R_3}$

Substituting the value in the equation (1)

$$I = I_1 + I_2 + I_3$$

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

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

Heating Effect of Electric Current

When electric energy is supplied to an electric bulb, the filament gets heated because of which it gives light. The heating of electric bulb happens because of heating effect of electric current.

When an electric iron is connected to an electric circuit, the element of electric iron gets heated because of dissipation of electric energy, which heats the electric iron. The element of electric iron is a purely resistive conductor. This happens because of heating effect of electric current.

Cause of heating effect of electric current:

Electric current generates heat to overcome the resistance offered by the conductor through which it passes. Higher the resistance, the electric current will generate higher amount of heat. Thus, generation of heat by electric current while passing through a conductor is an inevitable consequence. This heating effect is used in many appliances, such as electric iron, electric heater, electric geyser, etc.

Joule's Law of Heating:

The heat produced in a resistor is directly proportional to the square of current given to the resistor, directly proportional to the resistance for a given current and directly proportional to the time for which the current is flowing through the resistor.

Example 1: If an electric heater consumes electricity at the rate of 500W and the potential difference between the two terminals of electric circuit is 250V, calculate the electric current and resistance through the circuit.

Solution: *Given, power input (P) = 500 W*
Potential difference (V) = 250 V
Electric current (I) =?
Resistance (R) through the circuit =?

We know that power (P)=VI

Or, 500W=250V×I500W=250V×I

Or, I= 500W ÷ 250V = 2A

We know, resistance R=VI

Or, R=250V ÷ 2A=125Ω

Practice Questions:

- Compute the heat generated while transferring 96000 coulomb of charge in one hour through a potential difference of 50 V.
- An electric iron of resistance 20 W takes a current of 5 A. Calculate the heat developed in 30 s.

Electric Power:

The rate at which electrical energy is dissipated or consumed in an electric circuit. This is also termed as electric power.

The power P is given by

$$P = VI$$

Or $$P = I^2R = V^2/R$$

The SI unit of electric power is ***watt (W).*** It is the power consumed by a device that carries 1A current when operated at a potential difference of 1 V. Thus,

1 W = 1 volt x 1 ampere = 1 V A

One watt hour is the energy consumed when 1 watt of power is used for 1 hour. The commercial unit of electric energy is kilowatt hour (kW h), commonly known as 'unit'.

1 kW h = 1000 watt x 3600 second

= 3.6 x 10^6 watt second

= 3.6 x 10^6 joule (J)

Problem:

An electric refrigerator rated 400 W operates 8 hour/day. What is the cost of the energy to operate it for 30 days at Rs 3.00 per kW h?

Solution:

The total energy consumed by the refrigerator in 30 days would be

400 W x 8.0 hour/day x 30 days = 96000 W h = 96 kW h

Thus the cost of energy to operate the refrigerator for 30 days is

96 kW h x Rs 3.00 per kW h = Rs 288.00

Practice Question:

- An electric motor takes 5 A from a 220 V line. Determine the power of the motor and the energy consumed in 2 h.
- Compare the power used in the 2 W resistor in each of the following circuits:

(i) A 6 V battery in series with 1 W and 2 W resistors, and

(ii) A 4 V battery in parallel with 12 W and 2 W resistors