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Chapter – 11

Electricity

ELECTRIC CURRENT

When two charged bodies at different electric potentials are connected by a metal wire, then electric charges will flow from the body at higher potential to the one at lower potential (till they both acquire the same potential). This flow of charges in the metal wire constitutes an electric current. It is the potential difference between the ends of the wire which makes the electric charges (or current) to flow in the wire.

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

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

The SI unit of electric charge is coulomb (C), which is equivalent to the charge contained in nearly 6 × 10^{18} electrons. The electric current is expressed by a unit called ampere (A),

One ampere is constituted by the flow of one coulomb of charge per second, that is, 1 A = 1 C/1 s. Small quantities of current are expressed in milliampere

A smaller unit of current called "milliampere" is also used, which is denoted by mA.

1 milliampere =$\frac{1}{100}$ ampere

1 mA = 10^{-3} A

The very small quantities of current are expressed in a still smaller unit of current called microampere, μA

(1 μA = 10^{-6} A

Current is measured by an instrument called ammeter. The ammeter is always connected in series with the circuit in which the current is to be measured.

Flow' of charges inside a wire

The 'motion' of electrons in a conductor, however, is very different from that of charges in empty space. When a steady current flows through a conductor, the electrons in it move with a certain average 'drift speed'. One can calculate this drift speed of electrons for a typical copper wire carrying a small current, and it is found to be actually very small, of the order of 1 mm s-1. How is it then that an electric bulb lights up as soon as we turn the switch on? It cannot be that a current starts only when an electron from one terminal of the electric supply physically reaches the other terminal through the bulb, because the physical drift of electrons in the conducting wires is a very slow process

Potential difference

flow of charges in a conducting metallic wire, the gravity, of course, has no role to play; the electrons move only if there is a difference of electric pressure – called the potential difference – along the conductor. This difference of potential may be produced by a battery, consisting of one or more electric cells. The chemical action within a cell generates the potential difference across the terminals of the cell, even when no current is drawn from it.

When the cell is connected to a conducting circuit element, the potential difference sets the charges in motion in the conductor and produces an electric current. In order to maintain the current in a given electric circuit, the cell has to expend its chemical energy stored in it. We define the electric potential difference between two points in an electric circuit carrying some current as the work done to move a unit charge from one point to the other –

Potential difference (V) between two points = Work done (W)/Charge (Q)

V = W/Q

The SI unit of electric potential difference is volt (V),

One volt is the potential difference between two points in a current carrying conductor when 1 joule of work is done to move a charge of 1 coulomb from one point to the other

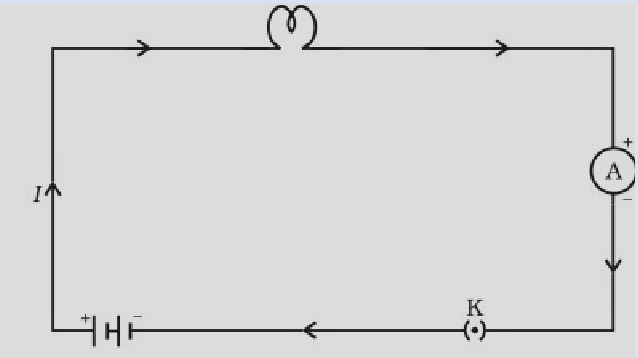
$$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$$

The potential difference is measured by means of an instrument called the voltmeter. The voltmeter is always connected in parallel across the points between which the potential difference is to be measured.

Circuit Diagrams

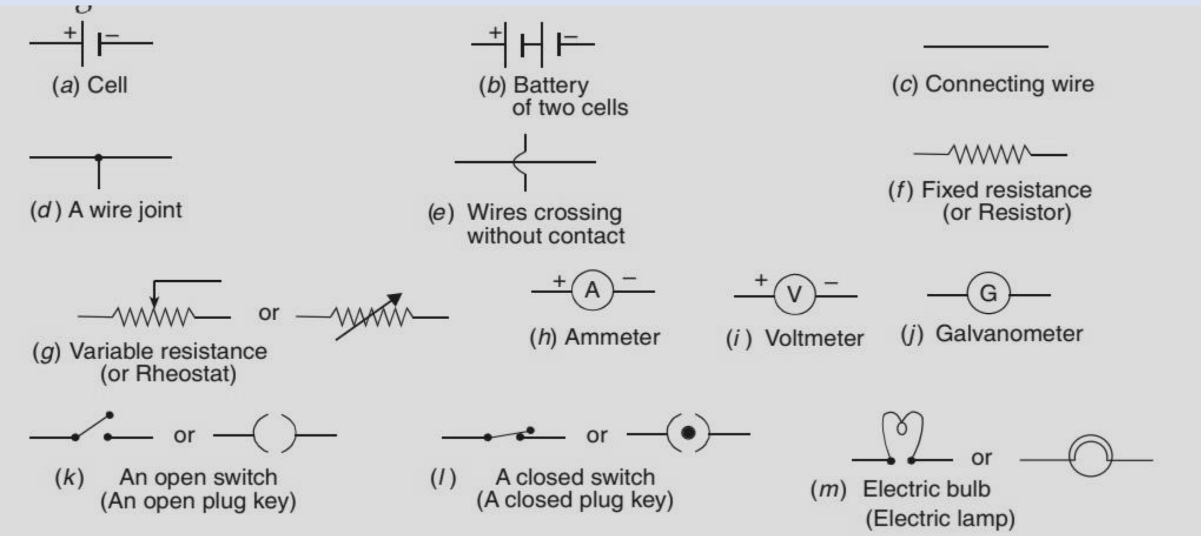
A diagram which indicates how different components in a circuit have been connected by using the electrical symbols for the components, is called a circuit diagram.

an electric circuit, comprises a cell (or a battery), a plug key, electrical component(s), and connecting wires. It is often convenient to draw a schematic diagram, in which different components of the circuit are represented by the symbols conveniently used. Conventional symbols used to represent some of the most used electrical components



Symbols for Electrical Components

the scientists have devised some symbols for electrical components which are easy to draw. They are called electrical symbols or circuit symbols. The common electrical symbols for electrical components which are used in drawing circuit diagrams are



OHM'S LAW

In 1827, a German physicist Georg Simon Ohm (1787–1854) found out the relationship between the current I, flowing in a metallic wire and the potential difference across its terminals. 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. This is called Ohm's law

$I \propto V$

This can also be written as : $V \propto I$

or $V = R \times I$

R is a constant for the given metallic wire at a given temperature and is called its resistance. It is the property of a conductor to resist the flow of charges

through it. Its SI unit is ohm, represented by the Greek letter Ω. According to Ohm's law,

$R = V/I$

If the potential difference across the two ends of a conductor is 1 V and the current through it is 1 A, then the resistance R, of the conductor is 1 Ω.

That is, 1 ohm = $\frac{1 \text{ volt}}{1 \text{ ampere}}$

the current through a resistor is inversely proportional to its resistance. If the resistance is doubled the current gets halved.

motion of electrons in an electric circuit constitutes an electric current. The electrons, however, are not completely free to move within a conductor. They are restrained by the attraction of the atoms among which they move. Thus, motion of electrons through a conductor is retarded by its resistance. A component of a given size that offers a low resistance is a good conductor. A conductor having some appreciable resistance is called a resistor. A component of identical size that offers a higher resistance is a poor conductor. An insulator of the same size offers even higher resistance

FACTORS AFFECTING THE RESISTANCE OF A CONDUCTOR

The electrical resistance of a conductor (or a wire) depends on the following factors :

(i) length of the conductor,
(ii) area of cross-section of the conductor (or thickness of the conductor),
(iii) nature of the material of the conductor, and
(iv) temperature of the conductor

resistance of a uniform metallic conductor is directly proportional to its length (l) and inversely proportional to the area of cross-section (A).

That is, $R \propto l$

and $R \propto 1/A$

Combining Eqs.

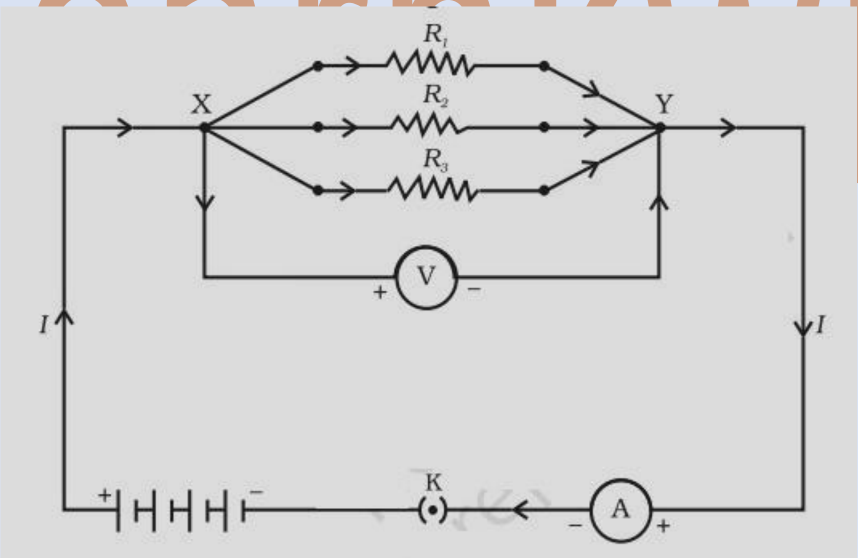
we get $R \propto \frac{1}{A}$

or, $R = \rho \frac{1}{A}$

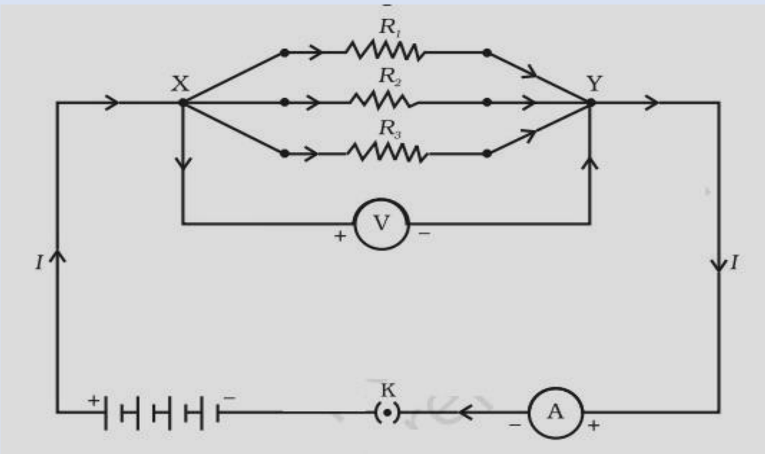
where ρ (rho) is a constant of proportionality and is called the electrical resistivity of the material of the conductor. The SI unit of resistivity is Ω m.

Resistance Of A System Of Resistors

There are two methods of joining the resistors together. an electric circuit in which three resistors having resistances R1, R2 and R3, respectively, are joined end to end. Here the resistors are said to be connected in series.

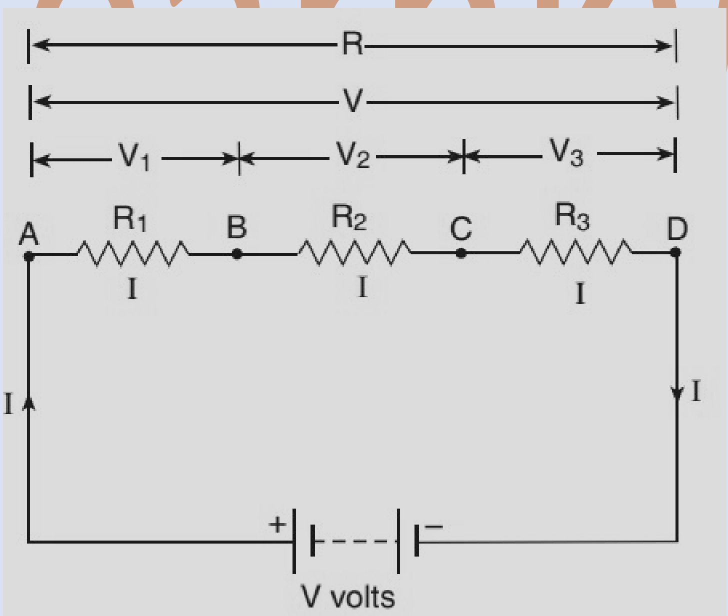


combination of resistors in which three resistors are connected between points X and Y. Here, the resistors are said to be connected in parallel



RESISTANCES (OR RESISTORS) IN SERIES

According to the law of combination of resistances in series : The combined resistance of any number of resistances connected in series is equal to the sum of the individual resistances.



Three resistances R1, R2 and R3 connected in series. A battery of V volts has been applied to the ends of this series combination of resistances. Now, suppose the potential difference across the resistance R1 is V1, the

potential difference across the resistance R2 is V2 and that across resistance R3 is V3.

We have applied a battery of voltage V, so the total potential difference across the three resistances should be equal to the voltage of the battery applied.

That is,

V = V1 + V2 + V3 1

the total potential difference due to battery is V. Now, let the total resistance (or resultant resistance) of the combination be R. The current flowing through the whole circuit is I. So, applying Ohm's law to the whole circuit, we get :

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

or V = I × R 2

the same current I flows through all the resistances R1, R2 and R3 in series, so by applying Ohm's law to each resistance separately, we will get :

$V_1 = I \times R_1$

$V_2 = I \times R_2$

$V_3 = I \times R_3$

Putting these values of V, V1, V2 and V3 in equation (1), we get

:I × R = I × R1 + I × R2 + I × R3

or I × R = I × (R1 + R2 + R3)

Cancelling I from both sides,

we get : R = R1 + R2 + R3

RESISTANCES (OR RESISTORS) IN PARALLEL

the total current flowing through the circuit is I, then the current passing through resistance R1 will be I1, the current passing through resistance R2 will be I2, and that through R3 will be I3.

It is obvious that

: Total current, I = I1 + I2 + I3 ... (1)

Suppose the resultant resistance of this combination is R. Then, by applying Ohm's law to the whole circuit, we get

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

Since the potential difference V across all the three resistances R_1**,** R_2 **and** R_3 **in parallel is the same, so by applying Ohm's law to each resistance separately, we get**

$I_1 = \frac{V}{R_1}$ 2

$I_2 = \frac{V}{R_2}$ 3

putting the values of I, I_1 **and** I_2

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

Cancelling V from both sides, we get :

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

HEATING EFFECT OF CURRENT

When an electric current is passed through a high resistance wire, like nichrome wire, the resistance wire becomes very hot and produces heat. This is called the heating effect of current.

Consider a current I flowing through a resistor of resistance R. Let the potential difference across it be V . Let t be the time during which a charge Q flows across. The work done in moving the charge Q through a potential difference V is VQ. Therefore,

the source must supply energy equal to VQ in time t. Hence the power input to the circuit by the source is

$$P = v\frac{Q}{t} = VI$$

Or the energy supplied to the circuit by the source in time t is P × t, that is, VIt.

for a steady current I, the amount of heat H produced in time t is

$$H = Vit$$

Applying Ohm's law

$$H = I^2Rt$$

This is known as Joule's law of heating. The law implies that heat produced in a resistor is (i) directly proportional to the square of current for a given resistance, (ii) directly proportional to resistance for a given current, and (iii) directly proportional to the time for which the current flows through the resistor. In practical situations, when an electric appliance is connected to a known voltage source, is used after calculating the current through it, using the relation I = V/R.

ELECTRIC POWER

When an electric current flows through a conductor, electrical energy is used up and we say that the current is doing work. We know that the rate of doing work is called power, so electric power is the electrical work done per unit time.

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 1 A of current when operated at a potential difference of 1 V.

Thus, 1 W = 1 volt × 1 ampere = 1 V A

The unit 'watt' is very small. Therefore, in actual practice we use a much larger unit called 'kilowatt'. It is equal to 1000 watts. Since electrical energy is the product of power and time, the unit of electric energy is, therefore, watt hour (W h). 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 × 3600 second

= 3.6 × 10^6 watt second

= 3.6 × 10^6 joule (J)