

J S U N I L      T U T O R I A L  
PANJABI COLONY, GALLI NO. 01

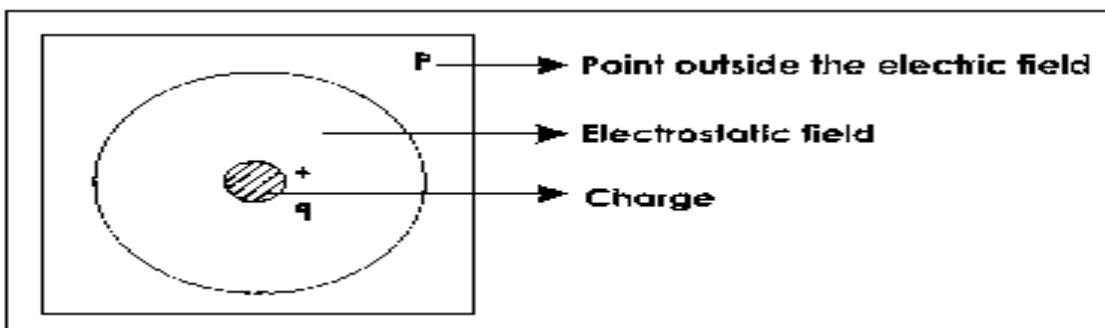
**Electric current Class x**

Electric Potential and Potential Difference

Let us consider the process of depositing an electric charge, for example, a positive charge on a neutral body. Initially it acquires a small amount of charge. If we wish to deposit some more charge of the same type on that body, it will experience a force of repulsion due to the charges already present on it. Therefore, work has to be done to counter this force of repulsion. This work done on the electrical charge in the process of charging gets stored as potential energy of charges. This is known as 'electrostatic potential'.

Electrostatic Potential

The electrostatic potential is defined as the work done in bringing a single positive charge from infinity to a point in the electric field. Any point outside the electric field or space is called infinite point. The unit of potential is volt (V).



Electric potential is a physical quantity, the value of which at different points tells us the direction of the electric current. Electric current flows from a higher potential to lower potential. If work is done by the charge, then the potential at that point is negative. If work is done by the charge, then the potential at that point is negative. The amount of work done does not depend on the path chosen.

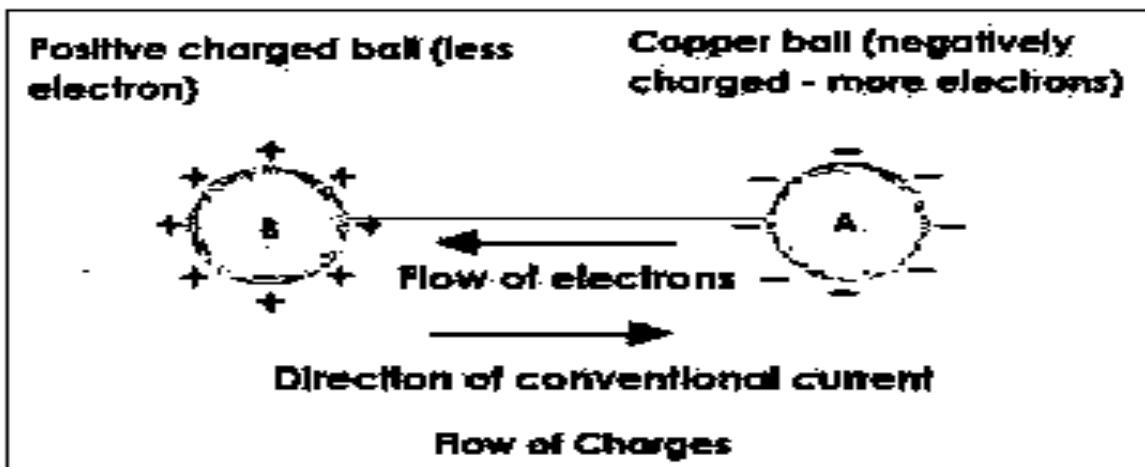
If the amount of work done in bringing 1 coulomb of charge from infinity to a given point in the electric field is 1 joule, then the potential at that point is said to be 1 volt.

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

Thus if a body is given Q coulomb of charge to raise its potential by V volt then the amount of work done will be VQ joule.  $W = VQ$

Two charged bodies of different potentials are placed one beside the other, the charges will not move from one body to the other. But if the two bodies are connected using a conductor, the flow of charges takes place. Charges will flow as long as there is potential

difference between the two bodies. This rate of flow of electric charge is called 'electric current'.



A conductor having excess electrons is said to be at a negative or at a lower potential and that having less electrons is said to be at a positive or at a higher potential. Under ordinary conditions the free electrons in a conductor move randomly in such a way that the net flow of charge across any section of the conductor is zero, no current exists in a conductor. If a potential difference is applied between the ends of conductor, the electrons are urged to flow from a point of lower potential to a point of higher potential. Thus there is a net flow of charge in this direction and hence a current flows in the opposite direction to that of electrons. Conventionally, the electric current is said to flow from a higher potential to a lower potential while the electrons flow from a lower potential to a higher potential i.e., the electric current flows in a direction opposite to the flow of electrons.

A simple way of maintaining potential difference between the two ends of a conductor is by connecting it to a battery or a dry cell. In a cell/battery the potential difference between its two electrodes is maintained by the chemical processes between its electrodes and the electrolyte. Therefore a cell is able to maintain a potential difference across a conductor.

#### Definition of Electric Current

The rate of flow of charge is called electric current or in other words the magnitude of the current  $I$  is the charge flowing in the circuit in one second. Mathematically expressed,

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

Where 'Q' is charge and 't' stands for time.

The unit of electric current is 'ampere' (A).

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

1 ampere = 1 coulomb/second

One ampere of current flow through a conductor, if one coulomb of charge flows in one second.

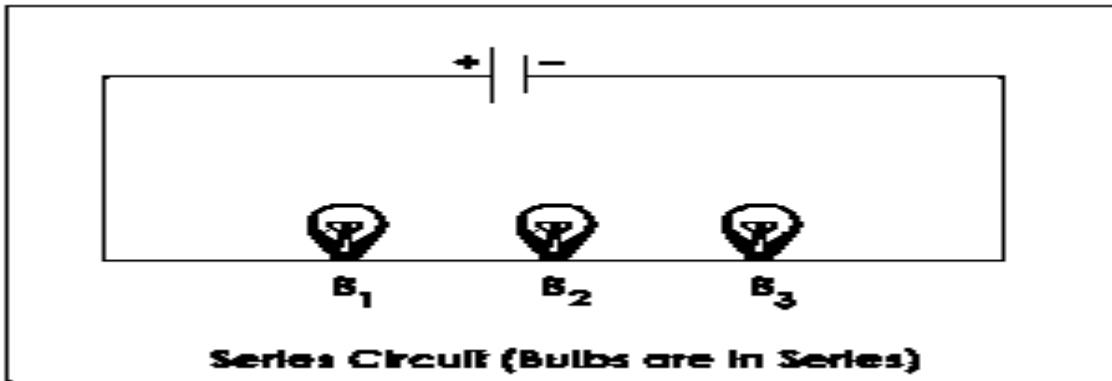
### Electric Circuits and their Components

The devices which deliver electricity are called the 'sources' and lamps, electric engines, etc. which consume electricity are called 'loads'. Switches are used to switch the loads on and off whenever necessary. Hence, the source, the load, and the switch are connected together to form electrical circuits.

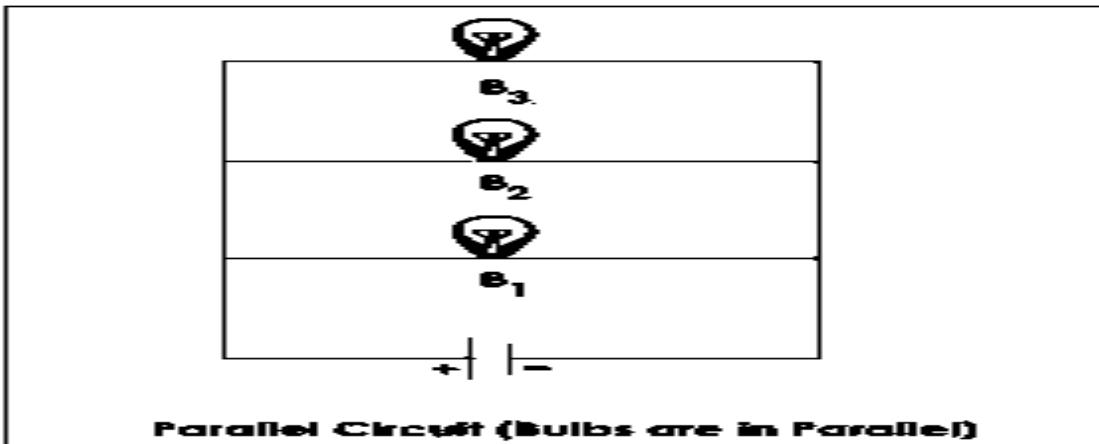
The circuit is called 'closed' when the current flows in the circuit, and when the current does not flow, it is called an 'open circuit'. The switch or key helps to make or break the circuit, i.e. switches on or switches off the current.

### Series and Parallel Circuits

If the components of a circuit are connected in a single loop, so that the same current flows through all the loads then the connection is called 'series' circuit.

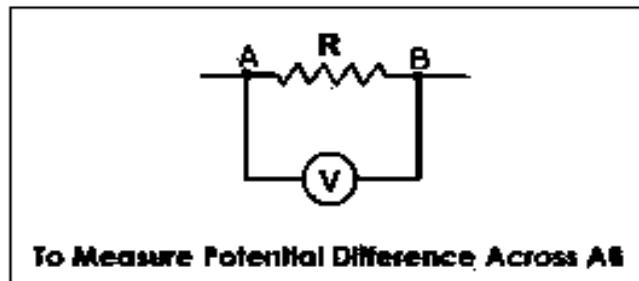
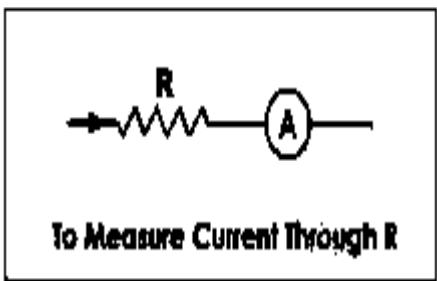


But, if each of the components has a separate connection with a battery, then the circuit is said to be in parallel. The potential difference across the elements remain same.



### Measuring Devices

A voltmeter is a device used to measure 'potential difference' and an ammeter is a device used to measure 'current'. Ammeters are connected 'in series' to the components through which the current to be measured flows. Voltmeters are connected in parallel to the components across which the potential difference is to be measured.



### Ohm's Law

In the year 1820 a French physicist, Andre Ampere made many discoveries on the nature of electricity. While a German physicist, George Ohm showed that the flow of electric current through a wire depended on its 'resistance' and the potential difference between its ends.

### Activity

Take a nichrome wire of about 50 cm length and apply a potential difference of 1.5 V from a battery. Measure the current flowing through the wire using an ammeter connected to it in series, and note the potential difference across the resistance using a voltmeter connected across it. Note down and tabulate the set of readings for I and V, by increasing the number of cells.

A graph drawn between the voltmeter readings and ammeter readings, shows a straight line pattern. The straight line indicates a linear relationship V and I.

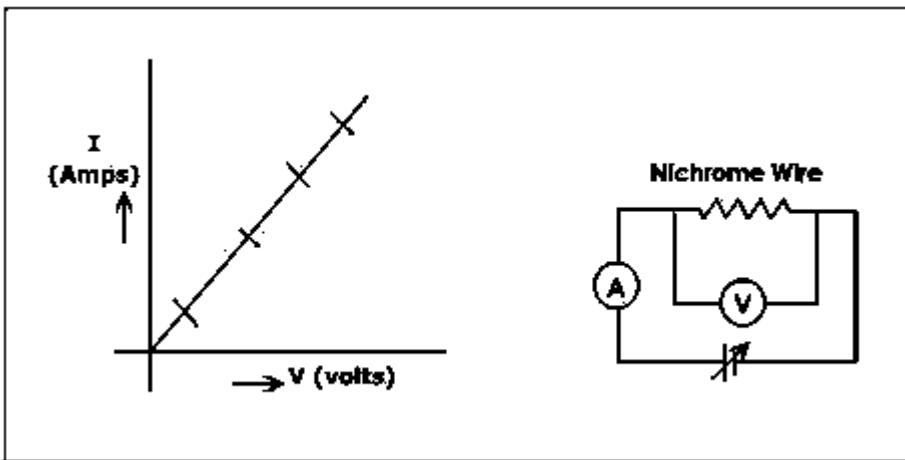
This relationship between V and I is known as ohm's law.

Mathematically this relationship can be expressed as,

$$V \propto I \quad V = RI$$

Where R is the constant of proportionality and gives the resistance offered by a conductor.

$$\text{Or } \frac{V}{I} = \text{constant}$$



If the above activity is repeated with another wire or a torch bulb, the current values are found to be different in each case. This shows that the current through the circuit is not decided by the battery but by the component through which it passes. Some materials allow larger current through them than others. In other words certain materials offer more resistance to the flow of current than others. The property by virtue of which a material opposes or limits the flow of electric current through it, is called its 'electric resistance'.

## Resistance

The resistance of a conductor may be defined in terms of current passing through it and the potential difference across its ends. Resistance of a wire is the ratio of the potential difference 'V' across its ends and the current 'I' flowing through it.

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

The unit of resistance is called the ohm, named after George Simon ohm, who found the relationship between current and potential difference. This law is called 'ohm's law'.

### Statement of Ohm's Law

The current through a metallic element is proportional to the potential difference between its ends, provided the temperature of the element remains constant.

Unit of resistance is 'ohm'

Ohm is the SI unit of resistance. The Greek letter omega ( $\Omega$ ) is used to represent resistance.

### Definition of Ohm

One ohm is the resistance of a conductor through which a current of 1 ampere flows when the potential difference across its ends is 1 volt.

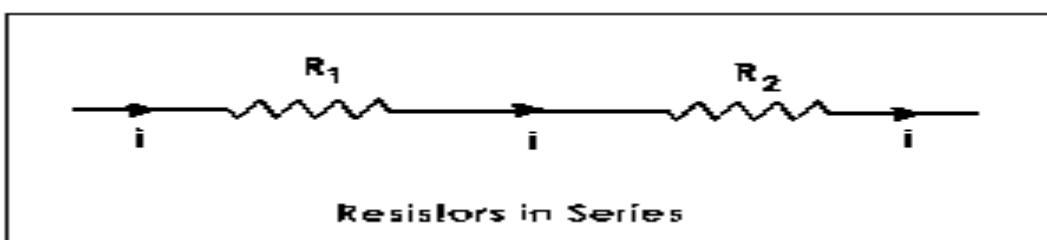
Conductors and Insulators

Substances which allow electricity to pass through them easily are called conductors. These are made from materials which have low resistances. Metals like copper, aluminium, silver, iron, brass and also salt solutions are good conductors of electricity.

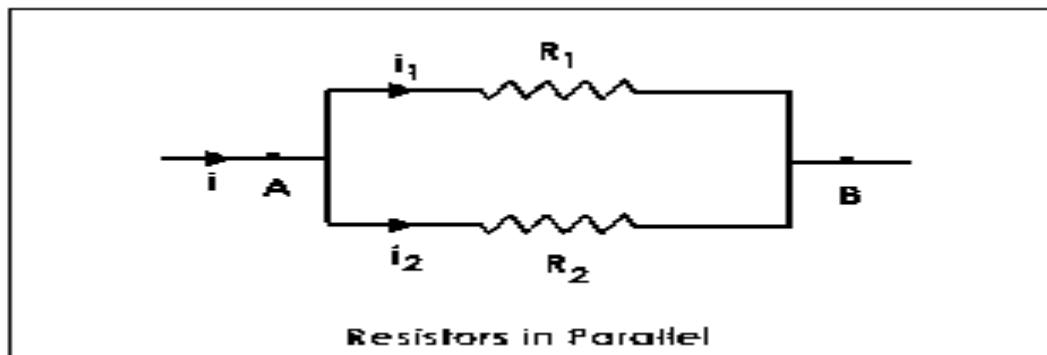
Substances which do not allow electricity to pass through them easily are called insulators. These are made from materials which have a high resistance. Some substances like air, plastic, cotton, rubber, wood, paper, glass, pure water, etc are insulators.

### Combination of Resistors in Series and Parallel

Resistors can be combined in different ways. When two or more resistors are connected end to end consecutively, so that the same current flows through all of them then, the resistors are said to be in series.



On the other hand if they are connected in such a way that the potential difference across them remains the same, they are said to be connected in parallel.



### Factors Affecting Resistance

The resistance of a conductor is affected by the following factors:

- i. Length of the Conductor

Resistance of a conductor is directly proportional to the length of the wire i.e., longer the wire greater will be the resistance and shorter the wire smaller will be the resistance. If  $L$  represents the length of the uniform wire, then  $R \propto L$

- ii. Area of the Cross-Section of the Conductor

Resistance of a conductor is inversely proportional to the area of the cross-section of the uniform wire. That means thinner the wire greater the resistance and thicker the wire lower the resistance. If A is the area of cross-section of the uniform wire, then

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

By combining both the factors,

$$R \propto \frac{L}{A} \quad \text{or} \quad R = \rho \frac{L}{A}$$

where  $\rho$  is the constant of proportionality called the resistivity of the material of the wire.

$$\rho = \frac{AR}{L}; \text{ If } A = 1 \text{ m}^2, L = 1 \text{ m}, \text{ then } \rho = R$$

Resistivity of a material is the resistance between the ends of a conductor of length one metre and area of cross-section of one square - metre. Unit of  $\rho$  (resistivity) is Ohm-metre ( $\Omega \text{ m}$ )

In other words, resistivity of a material is the resistance between the opposite faces of a unit cube of that material.

Note

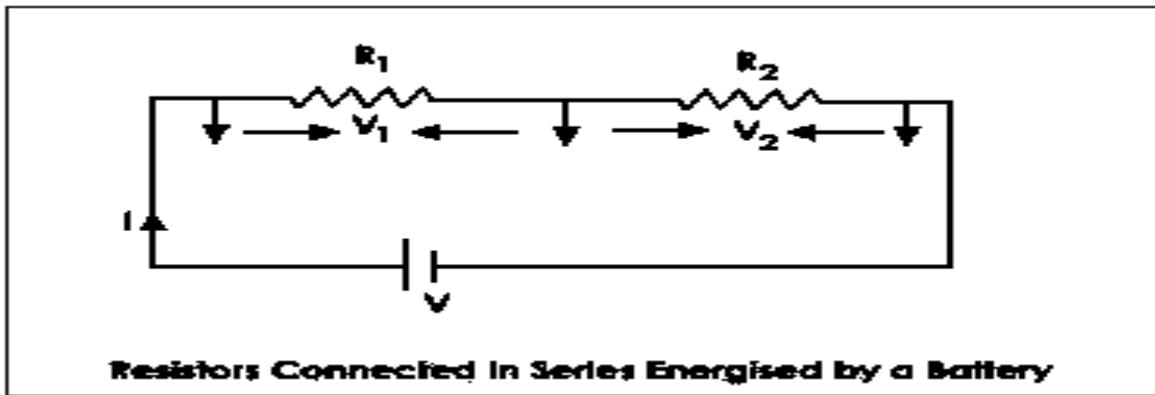
Good conductors possess low resistivity.

### **Effect of Temperature**

The effect of temperature has already been discussed earlier under limitations of ohm's law. In general for metallic conductors higher the temperature larger is the resistance.

### **Law of Combination of Resistors in Series**

Let us consider two resistors ' $R_1$ ' and ' $R_2$ ' connected in series. A battery of 'V' volts is applied to the ends of this series combination. Let us name the potential difference across  $R_1$  as  $V_1$ , and that across  $R_2$  as  $V_2$ . Since 'V' represents energy, according to the law of conservation of energy  $V = V_1 + V_2$  \_\_\_\_\_(1)



i.e., the total potential difference across the two resistors should be equal to the voltage of the battery.

Using Ohm's law,

$$V = IR \text{ ----- (1)}$$

$$V_1 = IR_1 \text{ and } V_2 = IR_2 \text{ ----- (2)}$$

where  $I$  is the current flowing through the circuit and ' $R$ ' represents the equivalent resistance of the two resistances.

Substituting (2) in (1)

$$IR = IR_1 + IR_2$$

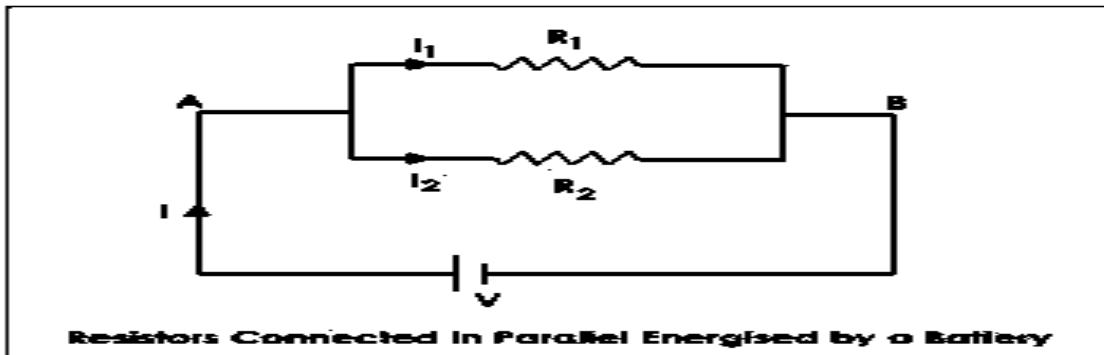
$$\Rightarrow R = R_1 + R_2$$

Inference

The equivalent resistance is the sum of the individual resistances connected in series. The above result can be generalised for ' $n$ ' number of resistances of different values as  $R = R_1 + R_2 + \dots + R_n$ .

### Law of Combination of Resistors in Parallel

Connect two resistors ' $R_1$ ' and ' $R_2$ ' in parallel to one another between the points A and B. Connect this combination to a battery of potential ' $V$ '.



Here the potential difference across  $R_1$  and  $R_2$  will be equal to battery voltage. But the total current  $I$  flowing in the circuit branches as  $I_1$  through  $R_1$  and  $I_2$  through  $R_2$ .

Since there cannot be accumulation of charges at any point

$$I = I_1 + I_2 \quad \text{---(1)}$$

Using Ohm's law,

$$I = \frac{V}{R}, I_1 = \frac{V}{R_1}, I_2 = \frac{V}{R_2} \quad \text{---(2)}$$

Substituting the above set of equations (2) in equation (1) we get

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} = V \left[ \frac{1}{R_1} + \frac{1}{R_2} \right] \quad \text{---(3)}$$

$$\text{Divide equation (3) throughout by } V \text{ we get } \Rightarrow \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

## Inference

If the resistors are connected in parallel, the reciprocal of the equivalent resistance is equal to the sum of the reciprocals of all the individual resistances. This result can be generalised for any  $n$  resistors.

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

From the above derivations we find that if we want to increase the resistance we should connect them in series and if we want to decrease the resistance then the individual resistors should be connected in parallel, in the circuit.

## Heating Effect of Electric Current

Energy exists in various forms such as mechanical energy, heat energy, chemical energy, electrical energy, light energy and nuclear energy. According to the law of conservation of energy, energy can be transformed from one form to another.

In our daily life we use many devices where electrical energy is converted into heat energy, light energy, chemical energy or mechanical energy. When an electric current is passed through a metallic wire like the filament of an electric heater, oven or geyser, the filament gets heated up and here the electrical energy is converted into heat energy. This is known as the 'heating effect of current'.

**Why is heat produced when current is passed through a wire?**

A metallic conductor has a large number of free electrons in it. When a potential difference is applied across the ends of a metallic wire, the free electrons begin to drift from a region of low potential to a region of high potential. These electrons collide with the positive ions (the atoms which have lost their electrons). In these collisions, the energy of the electron is transferred to the positive ions and they begin to vibrate more violently. As a result, heat is produced. The greater the number of electrons flowing per second, the greater will be the rate of collisions and so greater is the heat produced.

**Mathematical Expression for Heat Produced**

A potential difference is a measure of work done in moving a unit of charge across a circuit. Current in a circuit is equal to the amount of charge flowing in one second.

Therefore, the work done in moving 'Q' charges through a potential difference 'V' in a time 't' is given by      Work done = potential difference x current x time

$$\Rightarrow W = VIt$$

The same can be expressed differently using ohm's law.

According to ohm's law  $V = IR$

Therefore work can be expressed as

$$W = VIt$$

$$\text{or } W = (IR) It = I^2Rt$$

The work done 'W' gets dissipated in the resistors as heat energy H

$$\therefore H = I^2 Rt$$

Thus, heat produced is directly proportional to the resistance, to the time and to the square of the current.

$$\text{or } H = V \left( \frac{V}{R} \right) t = \frac{V^2}{R} t$$

### Application of the Heating Effect of Current

The heating effect of current is utilised in the electrical heating appliances such as electric iron, room heaters, water heaters, etc. All these heating appliances contain coils of high resistance wire made of nichrome alloy. When these appliances are connected to power supply by insulated copper wires then a large amount of heat is produced in the heating coils because they have high resistance, but a negligible heat is produced in the connecting wires because the wires have low resistance.

The heating effects of electric current is utilized in electric bulbs for producing light. When electric current passes through a thin high resistance tungsten filament of an electric bulb, the filament becomes white hot and emits light.

**An 'electric fuse'** is an important application of the heating effect of current. When the current drawn in a domestic electric circuit increases beyond a certain value, the fuse wire gets over heated, melts and breaks the circuit. This prevents fire and damage to various electrical appliances.

## Electric Power

Power is the rate of doing work or in other words, it is the work done in one second.

If a current of 'I' amperes flows through a conductor of resistance 'R' ohm for a time 't' seconds when the potential difference across its ends is 'V' volt, then the electric power consumed

$$P = \frac{\text{Work done}}{\text{time}} = \frac{W}{t} \quad P = \frac{VIt}{t} = VI$$

Using Ohm's law, 'Power' can also be expressed as

$$P = I^2R \quad \text{Or } P = \frac{V^2}{R}$$

The unit of power is 'watt'.  $\therefore 1 \text{ watt} = \frac{1 \text{ joule}}{1 \text{ second}}$

Thus if a potential difference of 1 volt causes a current of 1 ampere to flow through a wire, the electric power consumed by the wire is 1 watt.

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,

$$1 \text{ W} = 1 \text{ volt} \times 1 \text{ ampere} = 1 \text{ V A}$$

### Commercial Unit of Electrical Energy

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, watt hour (W h) can also be considered as unit of electric energy.

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 kWh is defined as the amount of electrical energy consumed in 1 hour when the rate of consumption is 1000 Joules/second

$$1 \text{ kW h} = 1000 \text{ watt} \times 3600 \text{ second}$$

$$= 3.6 \times 10^6 \text{ watt second}$$

$$= 3.6 \times 10^6 \text{ J}$$

## QUESTION ANSWER

**Question (1):** What is the SI unit of charge?

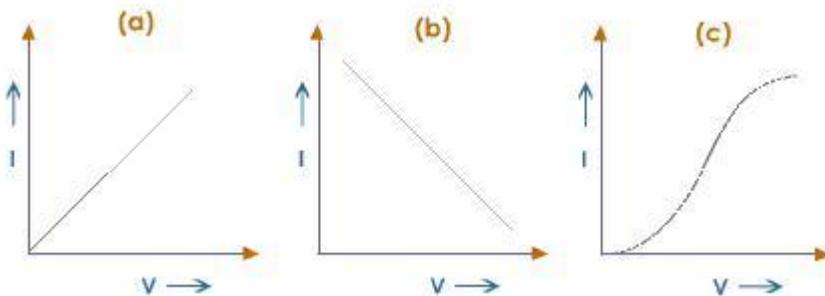
**Answer:** The SI unit of charge is coulomb.

**Question (2):** How many electrons constitute a charge equal to 1 C?

**Answer:** 1 Coulomb of charge has  $6.25 \times 10^{18}$  electrons.

**Question (3):** State ohm's law.

**Answer:** When temperature and other physical parameters remain constant, the current flowing through a conductor is directly proportional to the potential difference across its ends. **Question (4):** Which effect of current is used in the following appliance? a) electric bulb b) immersion rod c) electric iron d) galvanometer **Answer:** For electric bulb, immersion rod and electric iron, heating effect of current is used. For galvanometer magnetic effect of current is used. **Question (5):** Define watt and watt hour. **Answer:** Watt is the unit of power. If 1 joule of energy is consumed in 1 second, we say the power of the device is 1 watt. Watt hour is the unit of energy. If a device with a power 1 watt works for 1 hour 1 watt hour amount of energy is consumed. **Question (6):** Which of the following graphs depict ohm's law. **Answer:**



Graph (a) represents ohm's law since a straight line which shows that 'I' is directly proportional to 'V' (i.e., ohm's law). **Question (7):** Two coils have a combined resistance of 25 when connected in series and a resistance of 4 when connected in parallel. What is the resistance of each coil? **Answer:** Let the resistance be  $R_1$  and  $R_2$ , and  $R_s$  represents resistances in series and  $R_p$  represents resistance in parallel.

According to the given data

$$R_1 + R_2 = R_s = 25 \Omega \quad (1)$$

$$\frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{R_p} = \frac{1}{4}$$

$$\frac{R_2 + R_1}{R_1 R_2} = \frac{1}{4} \quad (2)$$

$$R_1 + R_2 = 25$$

$$R_1 R_2 = 100$$

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

$$= 25^2 - 4(100)$$

$$= 625 - 400$$

$$= 225$$

$$R_1 - R_2 = 15$$

$$R_1 + R_2 = 25$$

$$\text{Adding } 2R_1 = 40$$

$R_1 = 20$   $R_2 = 5$  **Question (8):** On what factor's does the heating effect of current depend on. **Answer:** The heating effect of current depends on

- The square of the amount of current flowing

- The resistance of the wire and
- The time of flow of current

**Question (9):** Name the instrument that measures the potential difference across the ends of a current carrying conductor. How is the instrument connected to the circuit? **Answer:**

Voltmeter measures the potential difference across the ends of a conductor. It is connected in parallel across the element through which current flows due to a certain potential difference. **Question (10):** When are several resistors in a circuit said to be connected in parallel? **Answer:** Several resistors are said to be connected in parallel when the potential difference across the resistors remain the same. **Question (11):** Two bulbs have ratings 100 W, 220 V and 60 W, 220 V respectively. Which one has a greater resistance? **Answer:**

$$P=VI$$

$$\frac{V^2}{R}$$

For the same V, R is inversely proportional to P. Therefore, the bulb 60 W, 220 V has a greater resistance. **Question (12):** A torch bulb has a resistance of

$1\Omega$  when cold. It draws a current of 0.2 A from a source of 2 V and glows. Calculate

(i) the resistance of the bulb when glowing and

(ii) explain the reason for the difference in resistance.

**Answer:** (i) When the bulb glows:

$$V = IR \text{ ---- Ohm's law}$$

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

$$= \frac{2}{0.2}$$

$$= 10\Omega$$

(ii) Resistance of the filament of the bulb increases with increase in temperature. Hence when it glows its resistance is greater than when it is cold. **Question (13):** Calculate the resistance of 1 km long copper wire of radius 1 mm. (Resistivity of copper =  $1.72 \times 10^{-8} \Omega \text{ m}$ ) **Answer:** L = 1 km = 1000 m

$$R = 1 \text{ mm} = 1 \times 10^{-3} \text{ m}$$

$$A = \pi r^2$$

$$= 3.14 \times (1 \times 10^{-3})^2$$

$$\rho = 1.72 \times 10^{-8} \Omega \text{m}$$

$$\text{Resistance of the wire } R = \rho \frac{L}{A}$$

$$R = 1.72 \times 10^{-8} \times \frac{1000}{3.14 \times (10^{-3})^2}$$

$R = 5.5\Omega$  **Question (14):** When a potential difference of 2 V is applied across the ends of a wire of 5 m length, a current of 1A is found to flow through it. Calculate: (i) the resistance per unit length of the wire (ii) the resistance of 2 m length of this wire (iii) the resistance across the ends of the wire if it is doubled on itself. **Answer:** (i)  $V = I R$  ----- Ohm's law

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

$$= \frac{2}{1}$$

$$= 2\Omega$$

$$\text{Resistance per unit length} = \frac{2\Omega}{5\text{m}} = 0.4\Omega \text{m}^{-1}$$

$$\text{(ii) Resistance of 2 m length of the wire} = 0.4 \times 2 \\ = 0.8\Omega$$

(iii) When the wire is doubled on itself:

(1) the area of cross-section is doubled. If A is the original C.S. area, now it is 2 A.

$$\text{(2) The length becomes half i.e. } \frac{L}{2}$$

$$\text{Resistance of this wire} = R' = \rho \frac{L/2}{2A}$$

$$= \rho \frac{L}{4A}$$

$$= \frac{1}{4} \cdot \rho \frac{L}{A}$$

But  $\rho \frac{L}{A} = 2\Omega$  (calculated in (i))

$$\therefore R' = \frac{1}{4} \times 2\Omega$$

$$= 0.5\Omega$$