

CHAPTER-12 ELECTRICITY

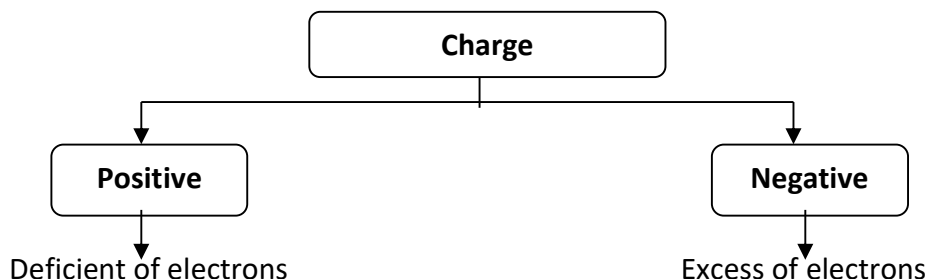
LEARNING OBJECTIVES:

Students will be able to:

- Define Electric current and its S.I. unit
- Recognize the symbols of electric circuit
- Identify the function of every component in the electric circuit
- Understand concept of Current, Potential difference, Resistance, Resistivity
- Understand the relationship between Electric current and potential difference
- Gain the skill to draw circuit diagram
- Solve numerical problems based on combination of resistance
- Understand the practical Applications of heating effect of current

ELECTRIC CHARGE (Q)

Definition	Electric charge is the fundamental property of an atom.
Formula	$Q = ne$ Where n = number of electrons e = charge on electron = 1.6×10^{-19} C
SI unit	Coulomb (C)

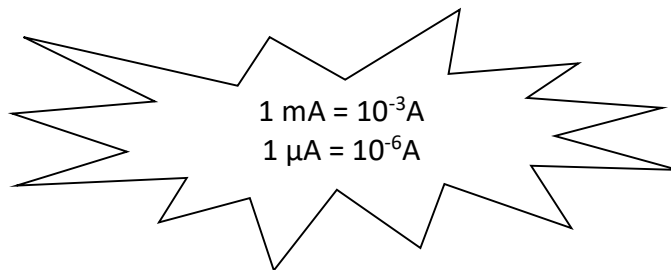


ELECTRIC CURRENT (I)

Definition	It is the rate of flow of electric charges.
Formula	$I = \frac{Q}{t}$ Where Q = net charge t = time for which the current flows in a conductor
SI unit	Ampere (A)
Definition of SI unit	One Ampere is constituted by the flow of one coulomb of charge per second. 1 ampere = 1 coulomb /1 second. 1 A = 1 C/s
Measuring instrument	Ammeter • Ammeter has low resistance and always connected in series.

Direction of electric current in a circuit

From the **positive** terminal of the cell to the **negative** terminal of the cell.


$$1 \text{ mA} = 10^{-3} \text{ A}$$
$$1 \text{ } \mu\text{A} = 10^{-6} \text{ A}$$

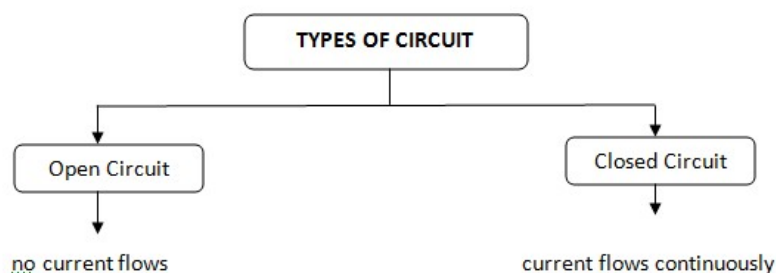
POTENTIAL DIFFERENCE (V)

Symbol	V
Definition	Work done to move a unit charge from one point to the other.
Formula	$V = \frac{W}{Q}$ Where W = Work done Q = charge
SI unit	Volt (V)
Definition of SI unit	When 1 joule work is done in carrying one Coulomb charge then potential difference is called 1 volt. 1 volt = 1 joule / 1 coulomb. 1 V = 1 J/C
Measuring instrument	Voltmeter It has high resistance and is always connected in parallel across the points between which the potential difference is to be measured.

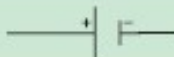
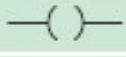
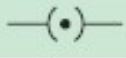
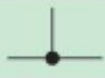
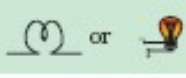
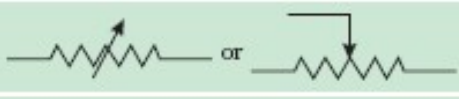
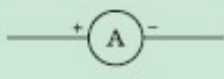
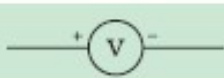
- Cell is the simplest device to maintain potential difference.

ELECTRIC CIRCUIT

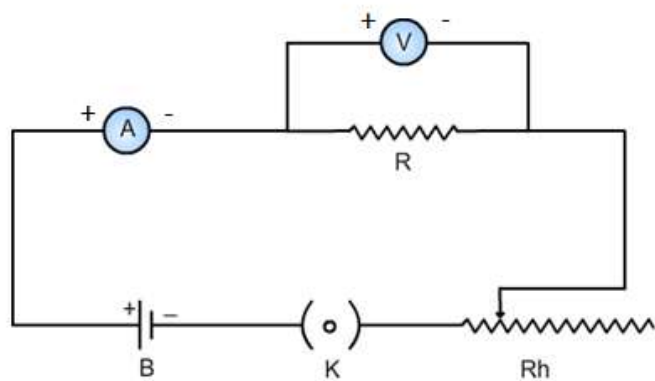
A closed and continuous path of an electric current is called an electric circuit.



SYMBOLS OF COMMONLY USED ELECTRICAL COMPONENTS

Sl. No.	Components	Symbols
1	An electric cell	
2	A battery or a combination of cells	
3	Plug key or switch (open)	
4	Plug key or switch (closed)	
5	A wire joint	
6	Wires crossing without joining	
7	Electric bulb	
8	A resistor of resistance R	
9	Variable resistance or rheostat	
10	Ammeter	
11	Voltmeter	

OHM'S LAW



An electric circuit to study Ohm's Law

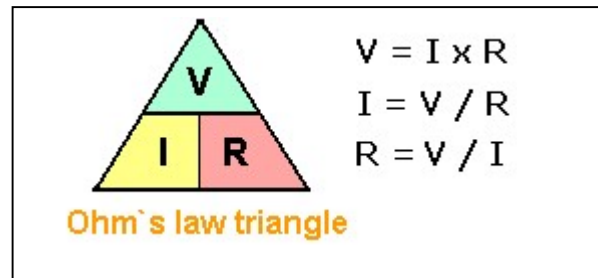
According to Ohm's law:

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.

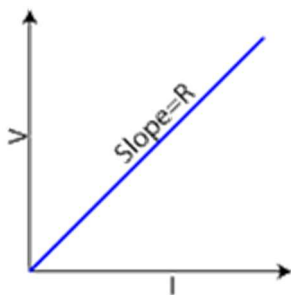
$$V \propto I$$

$$\text{or } V/I = \text{constant} = R \text{ (Resistance)}$$

$$\text{or } V = IR$$

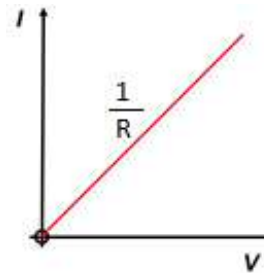


V-I GRAPH FOR OHM'S LAW



The slope of line V-I graph= Resistance (R)

I-V GRAPH FOR OHM'S LAW



The slope of line I-V graph= $\frac{1}{R}$

$$R = \frac{V_2 - V_1}{I_2 - I_1}$$

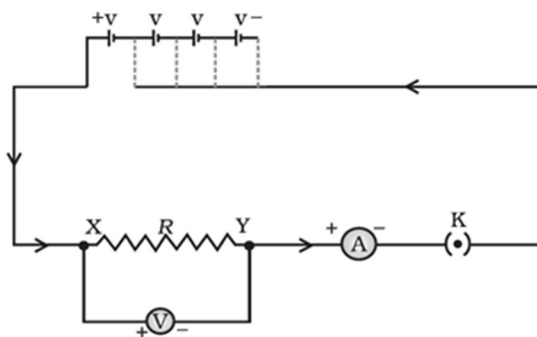
RESISTANCE (R)

Definition	It is the property of a conductor to resist the flow of charges through it.
Formula	$R = \frac{V}{I}$ Where V = Potential difference I = Current
SI unit	Ohm (Ω)
Definition of SI unit	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 of the conductor is 1 Ω . 1 ohm = $\frac{1 \text{ volt}}{1 \text{ ampere}}$

EXPERIMENTAL VERIFICATION OF OHM'S LAW

Aim: To verify Ohm's law experimentally.

Material Required: a nichrome wire of length XY, an ammeter, a voltmeter, a battery of four cells, a plug key (K)

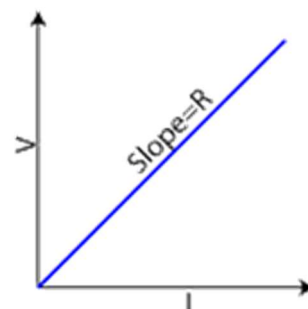


Procedure:

1. Set up a circuit as shown in the figure.
2. First use only one cell as the source in the circuit. Plug in the key and note the current and potential difference by noting ammeter and voltmeter readings respectively. Let these be I_1 and V_1 .
3. Next connect two cells in the circuit and note current I_2 and potential difference V_2 across the resistance.
4. Similarly take readings with three cells and four cells in the circuit.
5. From our observations we find that:

$$\frac{V_1}{I_1} = \frac{V_2}{I_2} = \frac{V_3}{I_3} = \frac{V_4}{I_4} = \text{constant} = R$$

6. If we plot a graph between V and I , the graph comes out to be straight line.



FACTORS ON WHICH THE RESISTANCE OF A CONDUCTOR DEPEND

Resistance of a conductor depends on:

- (i) its length (l)
- (ii) its area of cross-section (A)
- (iii) the nature of its material
- (iv) temperature of the conductor (Resistance increases with increase in temperature)

$$R \propto l \dots \dots \dots (1)$$

$$R \propto 1/A \dots \dots \dots (2)$$

Combining (1) and (2)

$$R \propto l/A$$

$$\Rightarrow R = \rho l / A$$

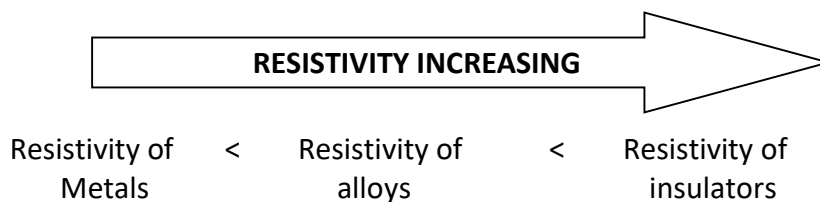
- ρ (rho) is a constant of proportionality and is called the **electrical resistivity** of the material of the conductor.

RESISTIVITY (ρ)

Definition	When $l=1\text{m}$, $A=1\text{m}^2$ then $\rho = R$ Resistivity is the resistance of the conductor of unit length and unit area of cross-section.
SI unit	Ωm

- Resistivity is a characteristic property of the material.
- It does not depend on length, shape and area of cross-section.
- It depends only on nature of material and temperature of conductor.

Metals & Alloys (order of $10^{-8} \Omega$ to $10^{-6} \Omega\text{m}$)	Insulators (order of 10^{12} to $10^{17} \Omega\text{m}$)
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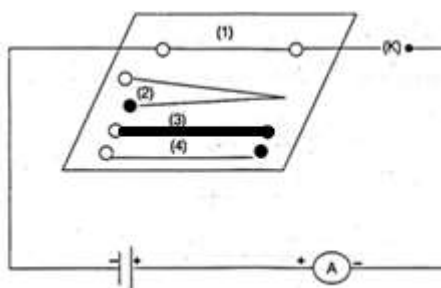
EXPERIMENT TO DEMONSTRATE THE FACTORS ON WHICH RESISTANCE OF CONDUCTING WIRE DEPENDS

Aim: To demonstrate the factors on which resistance of conducting wire depends

Material Required: a cell, an ammeter, a nichrome wire and a plug key.

Procedure:

1. Set up a circuit as shown in the figure.



2. Effect of length: Take the nichrome wire (1) of length l and connect it in the circuit. Now, plug the key K and note ammeter reading I_1 . Replace the nichrome wire by another nichrome wire (2) of same thickness but twice the length ($2l$) and note the ammeter reading I_2 . Experimentally, it is observed $I_2 = \frac{I_1}{2}$. It shows that resistance of 2nd wire is double of 1st wire. Thus, we conclude that

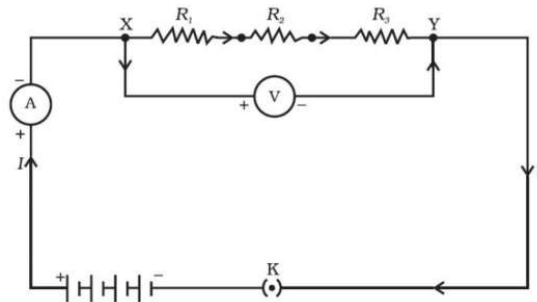
$$\frac{R_2}{R_1} = \frac{l_2}{l_1} = \frac{2l}{l} = 2 \text{ or } R \propto l$$

3. Effect of cross section area: Replace the nichrome wire by another nichrome wire (3) of length l but thickness more than wire (1). Put plug in key and note ammeter reading I_3 . It is more than I_1 . It means for a thicker wire (i.e. a wire of greater cross-section area) the resistance is less.

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

4. Effect of material: Now take the nichrome wire (4) of some other material but of length l and same thickness as wire (1). Connect the wire in the circuit and again note ammeter reading I_4 . We find that I_4 is different from I_1 . It shows that resistance depends on material of the conductor.

RESISTORS IN SERIES



In a series circuit,

- (a) the current I is the same in all parts of the circuit, and
- (b) the total potential difference across a combination of resistors in series is equal to the sum of potential difference across the individual resistors.

$$V = V_1 + V_2 + V_3 \dots\dots\dots(1)$$

From Ohm's law, $V = IR \dots\dots\dots(2)$

On applying Ohm's law to the three resistors separately, we further have

$$V_1 = IR_1 \dots\dots\dots(3)$$

$$V_2 = IR_2 \dots\dots\dots(4)$$

$$V_3 = IR_3 \dots\dots\dots(5)$$

Substituting (2), (3), (4), (5) in (1),

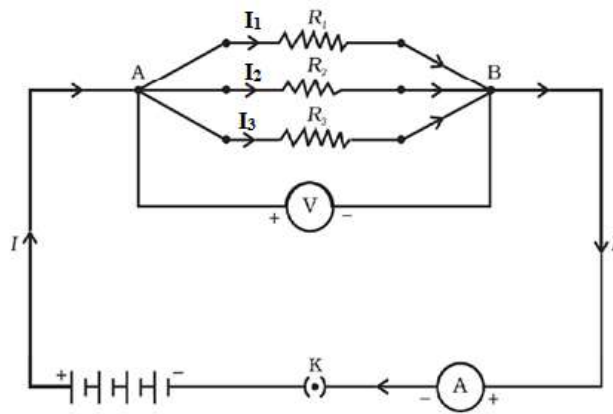
$$IR = IR_1 + IR_2 + IR_3$$

or

$$R_s = R_1 + R_2 + R_3$$

- When several resistors are joined in series, the resistance of the combination R_s equals the sum of their individual resistances R_1, R_2, R_3 .
- R_s is thus greater than any individual resistance.

RESISTORS IN PARALLEL



In a parallel circuit:

- (a) the potential difference V , across each resistor is same
- (b) the total current I , is equal to the sum of the separate currents through each branch of the combination.

$$I = I_1 + I_2 + I_3 \dots \dots \dots (1)$$

Let R_p be the equivalent resistance of the parallel combination of resistors. By applying Ohm's law to the parallel combination of resistors, we have

$$I = V/R_p \dots \dots \dots (2)$$

On applying Ohm's law to each resistor, we have

$$I_1 = V/R_1 \dots \dots \dots (3)$$

$$I_2 = V/R_2 \dots \dots \dots (4)$$

$$I_3 = V/R_3 \dots \dots \dots (5)$$

Substituting (2), (3), (4), (5) in (1),

$$V/R_p = V/R_1 + V/R_2 + V/R_3$$

$$1/R_p = 1/R_1 + 1/R_2 + 1/R_3$$

The reciprocal of the equivalent resistance of a group of resistances joined in parallel is equal to the sum of the reciprocals of the individual resistances.

Advantages of Parallel Combination over Series Combination/ Disadvantages of series combination

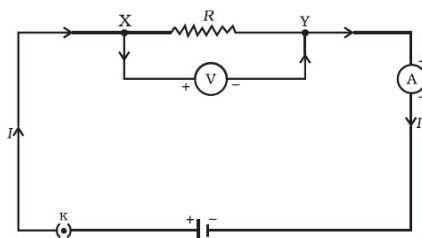
- (i) In series circuit, when one electrical component fails, the circuit is broken and none of the component works.
- (ii) Different appliances have different requirement of current. This cannot be satisfied in series as current remains same.
- (iii) Each appliance gets the same voltage (220V) as that of power supply line in parallel combination.
- (iv) In parallel combination each electrical component can have independent on/off switch.

HEATING EFFECT OF ELECTRIC CURRENT

The production of heat in a conductor due to the flow of electric current through it is called the **heating effect of electric current**. This effect is utilised in devices such as electric heater, electric iron etc.

Amount of heat produced in a conductor

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 is given by:

$$W = Q V \dots\dots\dots(1) \quad (\because V = W/Q)$$

Now,

$$Q = I t \dots\dots\dots(2) \quad (\because I = Q/t)$$

According to Ohm's law,

$$V = I R \dots\dots\dots(3)$$

Putting the values of (2) and (3) in (1)

$$W = I t \times I R$$

$$W = I^2 R t$$

This energy gets dissipated in the resistor as heat. Thus for a steady current I , the amount of heat H produced in time t is

$$H = I^2 R t$$

This is called **Joule's Law of Heating**, which states that the heat produced in a resistor is directly proportional to the

- Square of the current in the resistor, $H \propto I^2$
- Resistance of the resistor, $H \propto R$
- Time for which the current flows through the resistance, $H \propto t$

SI unit of heat: Joule (J)

OTHER FORMULAE FOR HEAT

$$H = I^2 R t = V I t = \frac{V^2 t}{R}$$

PRACTICAL APPLICATIONS OF THE HEATING EFFECTS OF ELECTRIC CURRENT

1. The electric laundry iron, electric toaster, electric oven, electric kettle and electric heater are some of the familiar devices based on Joule's heating.

2. **Electric bulb:** The electric heating is also used to produce light, in an electric bulb.

3. Fuse:

- Electric fuse is a safety device which protects circuits and appliances.
- Fuse is made up of pure tin or alloy of copper and tin.
- Fuse is always connected in series with live wire.
- Current capacity of fuse is slightly higher than that of the appliance.
- A fuse wire has low melting point. When high current passes through the fuse wire, it melts due to heating effect of current and circuit breaks, thereby protecting the appliance from high current damage.
- The fuses used for domestic purposes are rated as 1 A, 2 A, 3 A, 5 A, 10 A, 15 A etc.

Q. An electric oven of 2 kW power rating is operated in a domestic electric circuit which has a current rating 5A. If the supply voltage is 220V, what result do you expect? Explain.

$$P = 2 \text{ kW} = 2000 \text{ W}, V = 220 \text{ V}$$

$$P = V \times I$$

$$I = P/V = 2000/220 = 9.09 \text{ A.}$$

Current drawn is very high (9.09A) but the fuse is only of 5A. The fuse will blow off due to overloading cutting off the power supply in this circuit.

ELECTRIC POWER (P)

Definition	The rate of consumption of energy is called power.
Formula	$P = VI = \frac{V^2}{R} = I^2 R$
SI unit	Watt (W)
Definition of SI unit	1 watt : It is the power consumed by a device that carries 1 A of current when operated at a potential difference of 1 V. 1 watt = 1 volt x 1 ampere = 1 V A

COMMERCIAL UNIT OF ENERGY

The commercial unit of energy is kilowatt hour (kW h).

1 kilowatt hour is the energy used in one hour at the rate of 1 kilowatt (or 1000 J s).

$$1 \text{ kW h} = 1 \text{ kW} \times 1 \text{ h}$$

$$= 1000 \text{ W} \times 1 \text{ h}$$

$$= 1000 \text{ W} \times 3600 \text{ s} = 3600000 \text{ J}$$

$$1 \text{ kW h} = 3.6 \times 10^6 \text{ J}$$

The electrical energy used in homes and industries is expressed in kilowatt hour.

The electrical energy used during a month is expressed in 'units'.

Here 1 unit means 1 kilowatt hour.

Give reasons:

1. The connecting wires in an electric circuit are made up of copper and aluminium. (or)

Copper and aluminium are generally used for electrical transmission lines.

- Resistivity of copper and aluminium (pure metals) is low. Hence they are good conductors of electricity.
- Cheaper than silver.

2. Filament of electric bulb is made of tungsten metal.

- Melting point of tungsten is very high (3380 °C)
- It has high resistance, so a large heat is produced, ($H = I^2 R t$, Joule's law of heating)
- It does not burn (oxidize) even at high temperatures.

3. Heating elements of electric heating devices, such as bread-toasters and electric irons, are made of an alloy rather than pure metal

- Resistivity of an alloy is more than that of its constituent metals, due to which it produces large amount of heat on passing current ($H = I^2 R t$, Joule's law of heating)
- Alloys generally have high melting point.
- Alloys do not burn (oxidize) even at high temperatures.

4. Why do the wires connecting an electric heater to the mains not glow while its heating element does?

- The wires of the connecting cord of electric heater are made of Cu in which negligible heat is produced due to its extremely low resistivity.
- The heating element of an electric heater is made of nichrome wire. It glows because large amount of heat is produced due to its high resistivity ($H = I^2 R t$)

5. The bulbs are usually filled with chemically inactive nitrogen and argon gases

- to prolong the life of filament.