Electricity

CLASS-10TH CHAPTER-12TH

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- **E**lectricity has an important place in modern society.

- It is a controllable and convenient form of energy for a variety of uses in homes, schools, hospitals, industries and so on.

- What constitutes electricity? How does it flow in an electric circuit? What are the factors that control or regulate the current through an electric circuit?

- In this Chapter, we shall attempt to answer such questions. We shall also discuss the heating effect of electric current and its applications.

ELECTRIC CURRENT AND CIRCUIT

- We are familiar with air current and water current. We know that flowing water constitute water current in rivers.

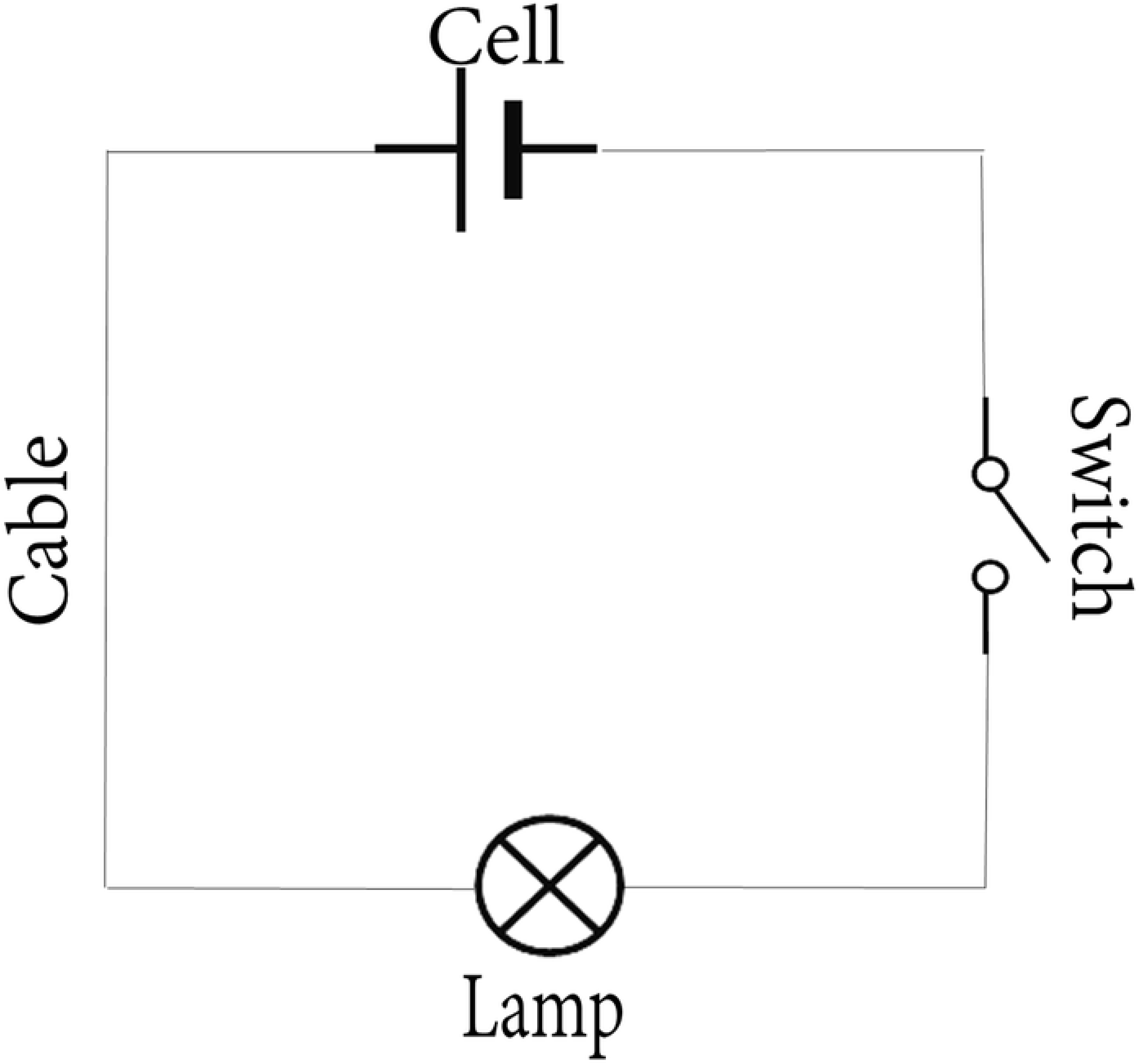
- Similarly, if the electric charge flows through a conductor (for example, through a metallic wire), we say that there is an electric current in the conductor.

- In a torch, we know that the cells (or a battery, when placed in proper order) provide
- flow of charges or an electric current through the torch bulb to glow.

- We have also seen that the torch gives light only when its switch is *on*. What does a switch do? A switch makes a conducting link between the cell and the bulb.

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

- Now, if the circuit is broken anywhere (or the switch of the torch is turned *off*), the current stops flowing and the bulb does not glow.


Cell
Cable
Switch
Lamp

- How do we express 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. In circuits using metallic wires, electrons constitute the flow of charges.

- However, electrons were not known at the time when the phenomenon of electricity was first observed.

- So, electric current was considered to be the flow of positive charges and the direction of flow of positive charges was taken to be the direction of electric current.

- Conventionally, 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

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

- The SI unit of electric charge is coulomb (C), which is equivalent to the charge contained in nearly 6 × 1018 electrons. (We know that an electron possesses a negative charge of 1.6 × 10–19 C.)

- The electric current is expressed by a unit called ampere (A), named after the French scientist, Andre-Marie Ampere (1775–1836).

- 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 (1 mA = 10–3 A) or in microampere (1 µA = 10–6 A). An instrument called ammeter measures electric current in a circuit.

- It is always connected in series in a circuit through which the current is to be measured.

- The schematic diagram of a typical electric circuit comprising a cell, an electric bulb, an ammeter and a plug key.

- Note that the electric current flows in the circuit from the positive terminal of the cell to the negative terminal of the cell through the bulb and ammeter

More to Know

‘Flow’ of charges inside a wire

How does a metal conduct electricity? You would think that a low-energy electron would have great difficulty passing through a solid conductor. Inside the solid, the atoms are packed together with very little spacing between them. But it turns out that the electrons are able to ‘travel’ through a perfect solid crystal smoothly and easily, almost as if they were in a vacuum. 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. The exact mechanism of the current flow, which takes place with a speed close to the speed of light, is fascinating, but it is beyond the scope of this book. Do you feel like probing this question at an advanced level?

ELECTRIC POTENTIAL AND POTENTIAL DIFFERENCE

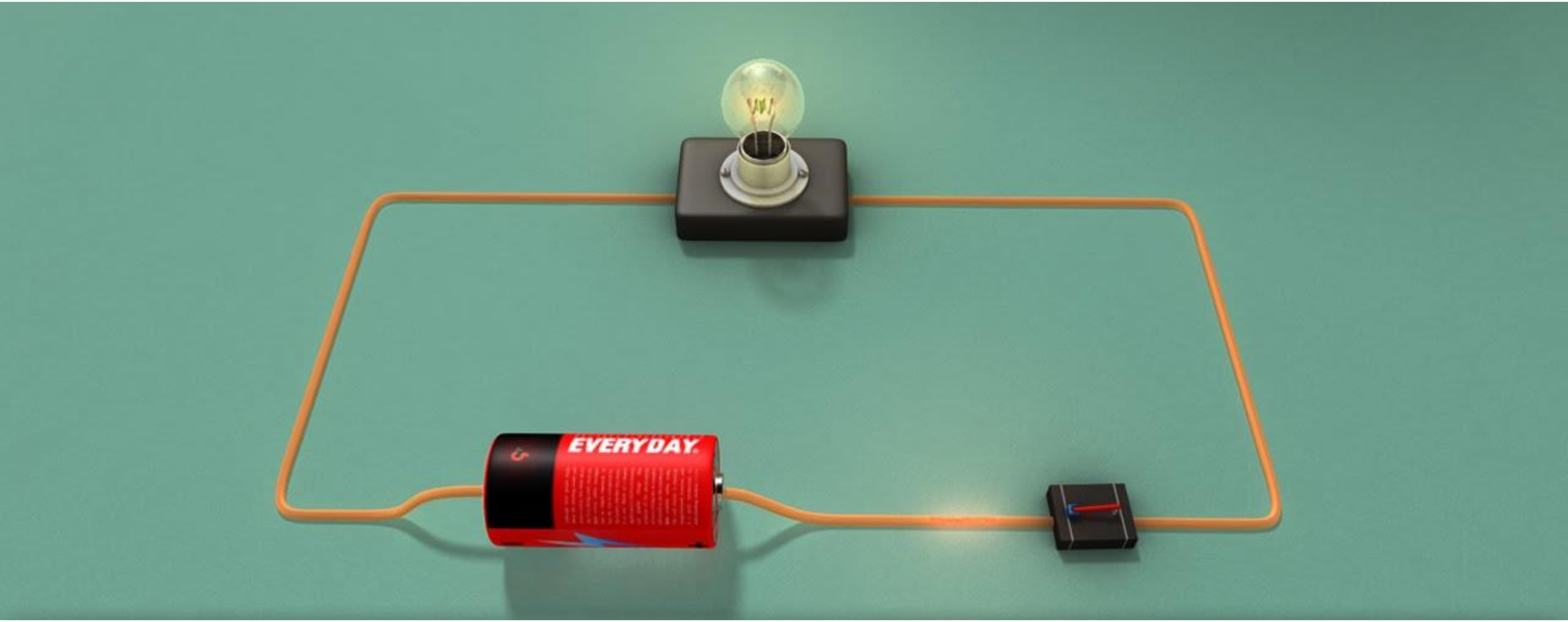
- What makes the electric charge to flow? Let us consider the analogy of flow of water.

- Charges do not flow in a copper wire by themselves, just as water in a perfectly horizontal tube does not flow.

- If one end of the tube is connected to a tank of water kept at a higher level, such that there is a pressure difference between the two ends of the tube, water flows out of the other end of the tube.

- For 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.


EVERYDAY

- 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), named after Alessandro Volta (1745–1827), an Italian physicist.

- 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.

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

- The potential difference is measured by means of an instrument called the voltmeter.

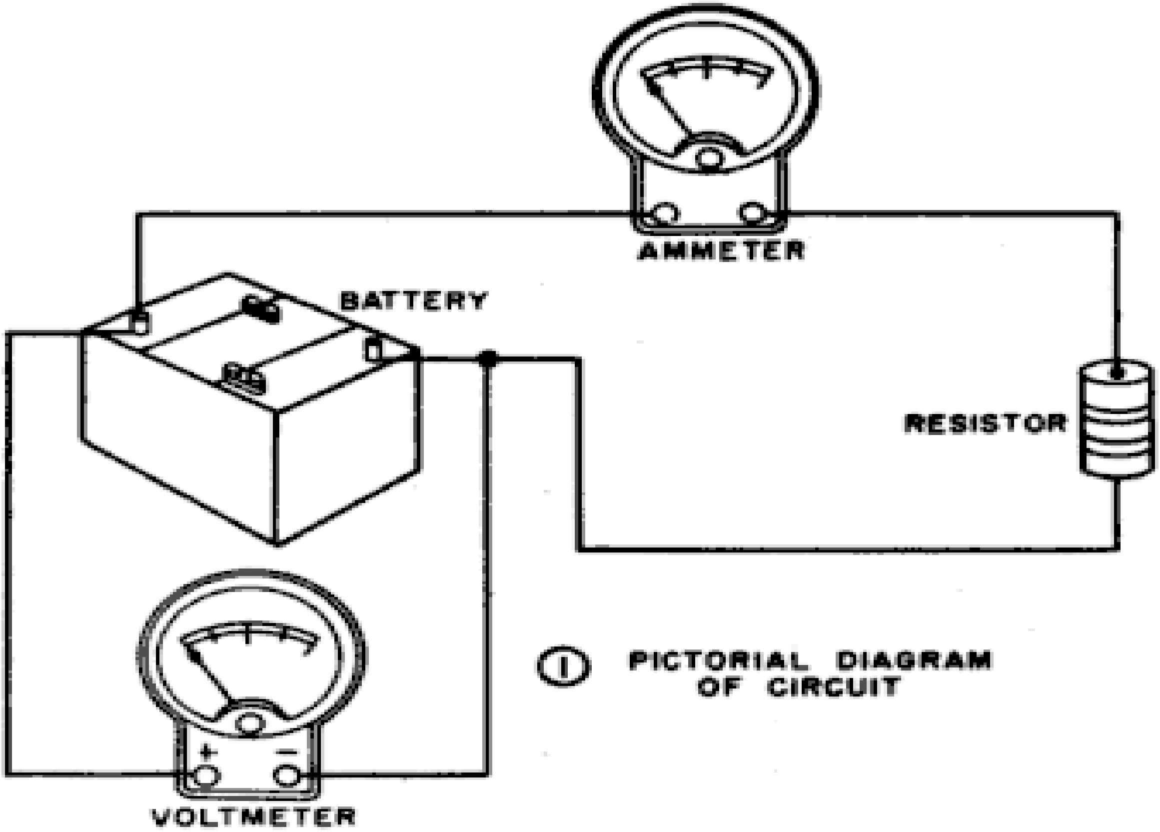
- The voltmeter is always connected in parallel across the points between which the potential difference is to be measured.

CIRCUIT DIAGRAM

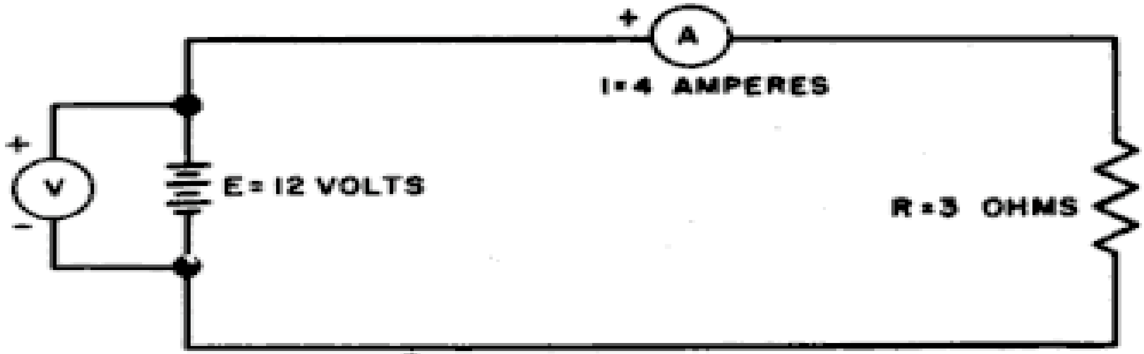
- We know that an electric circuit, comprises a cell (or a battery), a plug key, electrical component(s), and connecting wires.

- 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 commonly used electrical components.

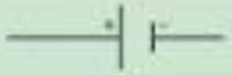
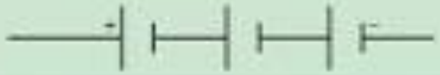
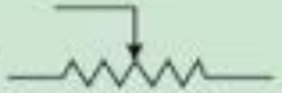


① PICTORIAL DIAGRAM OF CIRCUIT



② SCHEMATIC OF CIRCUIT

Symbols of some commonly used components in circuit diagrams

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	 or 
8	A resistor of resistance *R*	
9	Variable resistance or rheostat	 or 
10	Ammeter	
11	Voltmeter	

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. In other words –

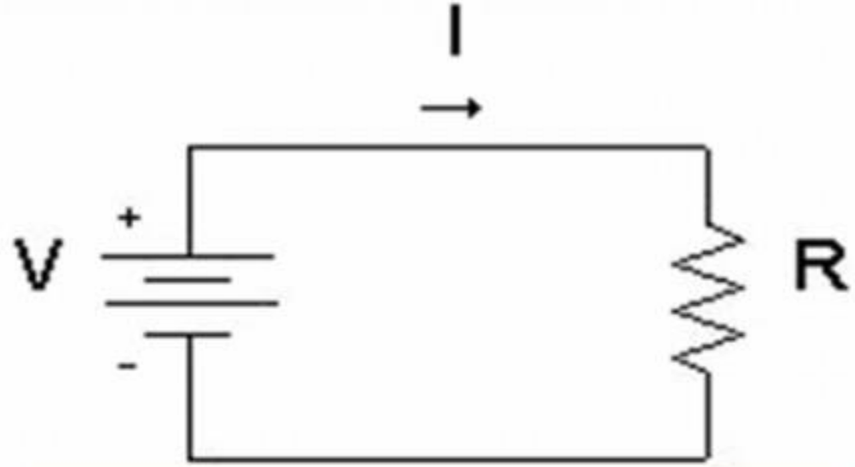
$V \propto I$

Or $V/I =$ constant

$= R$

Or $V = IR$

Georg Simon Ohm



Basic Electrical Circuit

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

Ohm's Law

In 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 W. 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 W.
- That is, 1 ohm = 1 volt

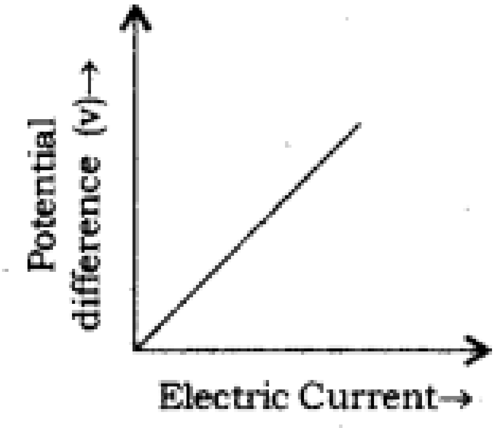
  1 ampere

1 Ohm:

- 1 ohm (Q) of resistance (R) is equal to the flow 1A of current through a conductor between two points having a potential difference equal to 1V.
  This means; 1Ω = 1V1A

- From the expression of Ohm's Law, it is obvious that electric current through a resistor is inversely proportional to resistance.

- This means electric current will decrease with an increase in resistance and vice versa. The graph of V (potential difference) versus I (electric current) is always a straight line.



Graph of Potential Difference (V) Vs Electric Current (I)

Voltage, i.e. Potential difference (V) = ?

We know, from Ohm’s Law that,

R = VI

15 Ω = V15A

V = 225V

FACTORS ON WHICH THE RESISTANCE OF A CONDUCTOR DEPENDS

It is observed that the ammeter reading decreases to one-half when the length of the wire is doubled. The ammeter reading is increased when a thicker wire of the same material and of the same length is used in the circuit. A change in ammeter reading is observed when a wire of different material of the same length and the same area of cross-section is used. On applying Ohm's law, we observe that the resistance of the conductor depends (i) on its length, (ii) on its area of cross-section, and (iii) on the nature of its material. Precise measurements have shown that 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,

$R \ \mu \ l$

and $R \ \mu \ 1/A$

Combining

$$R \ \mu \ \frac{l}{A}$$

or $$R = r \ \frac{l}{A}$$

where r (rho) is a constant of proportionality and is called the electrical resistivity of the material of the conductor.

The SI unit of resistivity is W m. It is a characteristic property of the material.

The metals and alloys have very low resistivity in the range of 10–8 W m to 10–6 W m.

They are good conductors of electricity. Insulators like rubber and glass have resistivity of the order of 1012 to 1017 W m.

Both the resistance and resistivity of a material vary with temperature.

The resistivity of an alloy is generally higher than that of its constituent metals. Alloys do not oxidise (burn) readily at high temperatures.

For this reason, they are commonly used in electrical heating devices, like electric iron, toasters etc.

- Tungsten is used almost exclusively for filaments of electric bulbs, whereas copper and aluminium are generally used for electrical transmission lines.

Resistivity of some common substances (20^0 C)

	Material	Resistivity (Ω m)
Conductors	Silver	1.60×10^{-8}
	Copper	1.62×10^{-8}
	Aluminium	2.63×10^{-8}
	Tungsten	5.20×10^{-8}
	Nickel	6.84×10^{-8}
	Iron	10.0×10^{-8}
	Chromium	12.9×10^{-8}
	Mercury	94.0×10^{-8}
	Manganese	1.84×10^{-6}
Alloys	Constantan (alloy of Cu and Ni)	49×10^{-6}
	Manganin (alloy of Cu, Mn and Ni)	44×10^{-6}
	Nichrome (alloy of Ni, Cr, Mn and Fe)	100×10^{-6}
Insulators	Glass	$10^{10} - 10^{14}$
	Hard rubber	$10^{13} - 10^{16}$
	Ebonite	$10^{15} - 10^{17}$
	Diamond	$10^{12} - 10^{13}$
	Paper (dry)	10^{12}

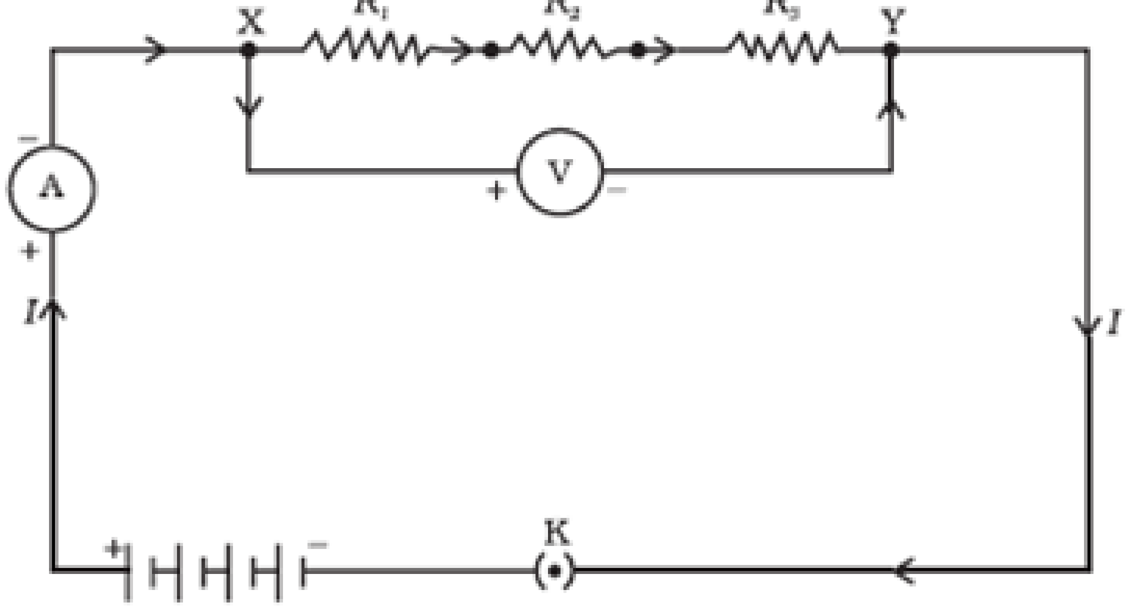
RESISTANCE OF A SYSTEM OF RESISTORS

- In preceding sections, we learnt about some simple electric circuits. We have noticed how the current through a conductor depends upon its resistance and the potential difference across its ends.

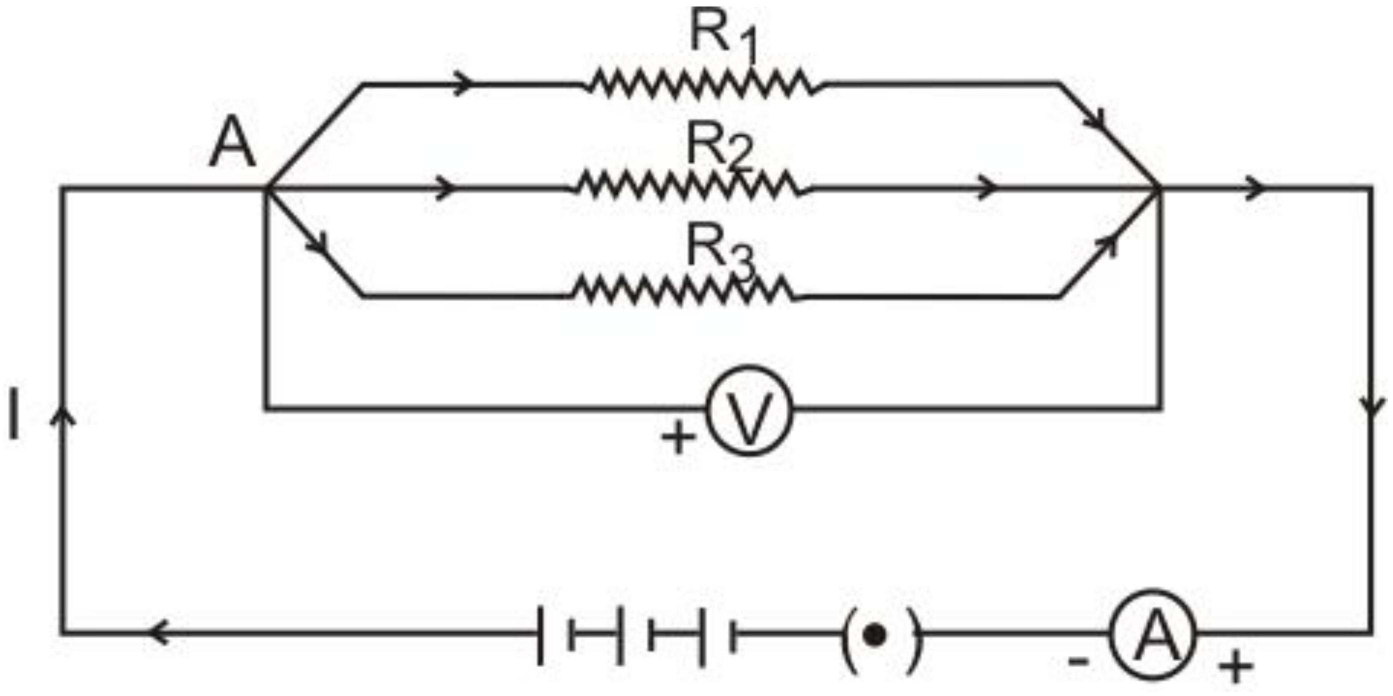
- In various electrical gadgets, we often use resistors in various combinations. We now therefore intend to see how Ohm's law can be applied to combinations of resistors.

- There are two methods of joining the resistors together. An electric circuit in which three resistors having resistances R_1, R_2 and R_3, respectively, are joined end to end.

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



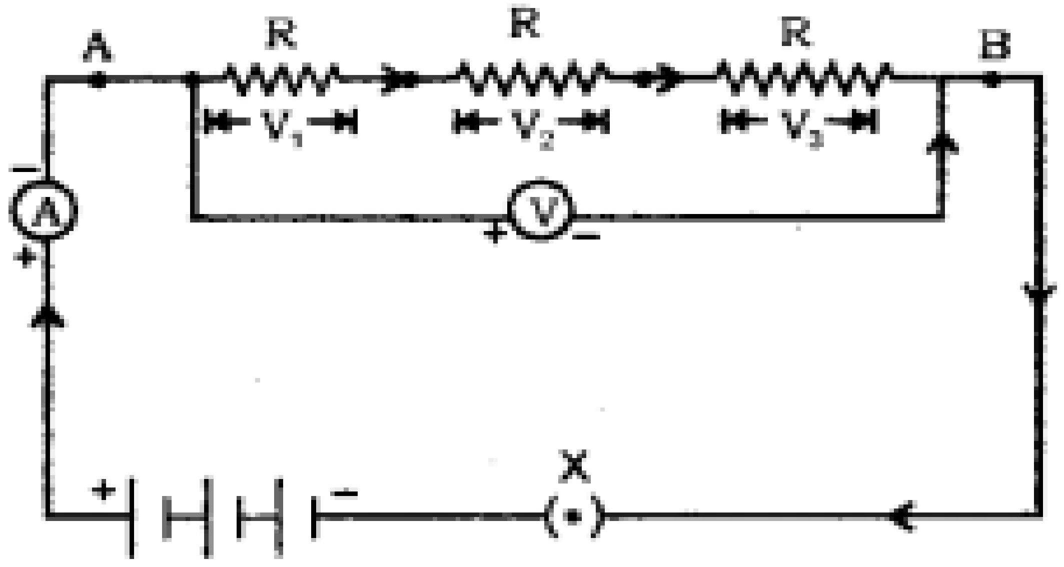
Resistors in series



Resistors in parallel

Resistors in Series

When resistors are joined from end to end, it is called in series. In this case, the total resistance of the system is equal to the sum of the resistance of all the resistors in the system.



Let, three resistors R1, R2, and R3 get connected in series.

Potential difference across A and B = V

Potential difference across R1, R2 and R3 = V1, V2 and V3

Current flowing through the combination = I

We, know that

$V = V1 + V2 + V3$ …. (i)

According to Ohm's Law :

$V1 = IR1$, $V2 = IR2$ and $V3 = IR3$ ….. (ii)

Let, total resistance = Rs

Then, $V = IRs$ …(iii)

From equations (i) and (ii) and (iii)

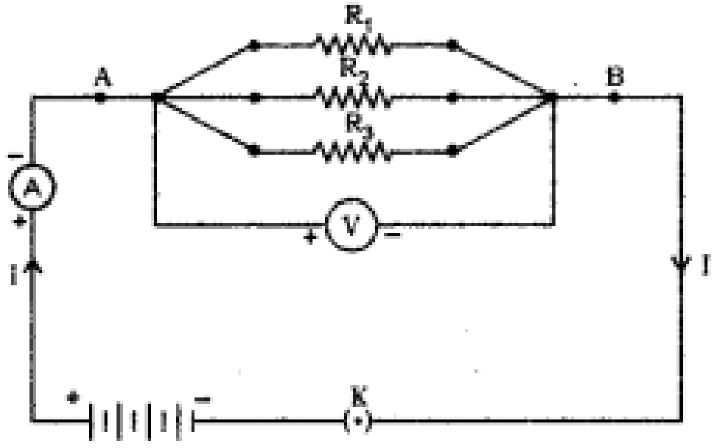
$IRs = IR1 + IR2 + IR3$

$Rs = R1 + R2 + R3$

When the resistors are connected in series, the current flowing through each resistor is the same and is equal to the total current.

Resistors in Parallel

When resistors are joined in parallel, the reciprocal of the total resistance of the system is equal to the sum of reciprocal of the resistance of resistors.



Let three resistors R1, R2 and R3 connected in parallel.

Potential difference across point A and B = V

Total current flowing between point A and B = I

Currents flowing through resistors R1, R2 and R3 = I1, I2 and I3 respectively.

We, know that,

I = I1 + I2 + I3 …….(i)

Since, the potential difference across R1, R2, and R3 is the same = V

According to Ohm’s Law,

$$I_1 = \frac{V}{R_1}, I_2 \frac{V}{R_2} \text{ and, } I_3 = \frac{V}{R_3} \quad ....(ii)$$

Let, Total Resistance = R_p

Thus, $I = \dfrac{V}{R_p}$ ...(iii)

From equations (i), (ii) and (iii)

$$\frac{V}{R_p} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \Rightarrow \frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad ...(iv)$$

- In parallel combination, the potential difference across each resistor is the same and is equal to the total potential difference.
- The total current through the circuit can be calculated by adding the electric current through individual resistors.
- Total = 6A + 48A + 30A + 12A + 24A = 120A

HEATING EFFECT OF ELECTRIC CURRENT

We know that a battery or a cell is a source of electrical energy.

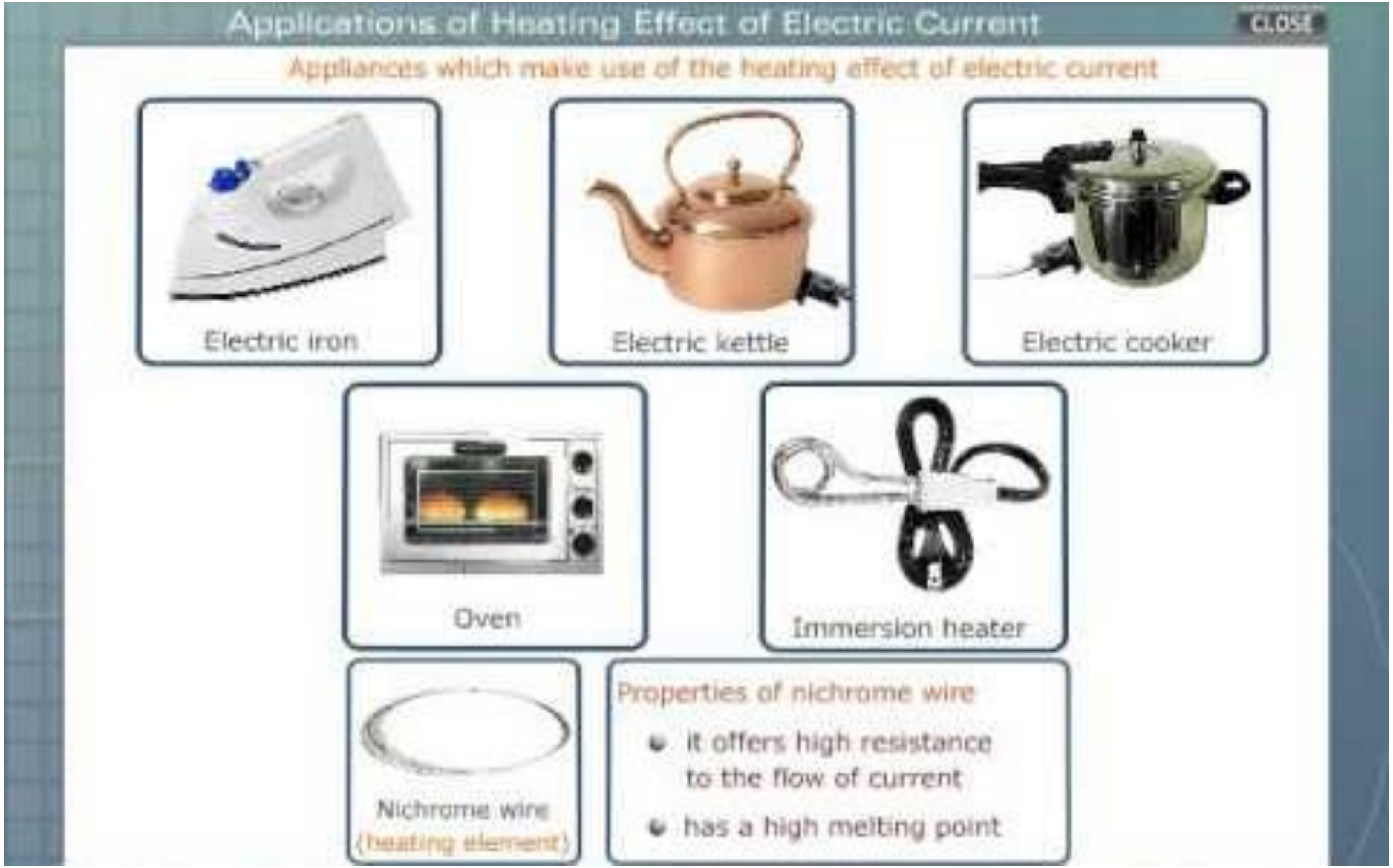
The chemical reaction within the cell generates the potential difference between its two terminals that sets the electrons in motion to flow the current through a resistor or a system of resistors connected to the battery.

Where does this energy go? A part of the source energy in maintaining the current may be consumed into useful work (like in rotating the blades of an electric fan).

Rest of the source energy may be expended in heat to raise the temperature of gadget. We often observe this in our everyday life.

For example, an electric fan becomes warm if used continuously for longer time etc.

On the other hand, if the electric circuit is purely resistive, that is, a configuration of resistors only connected to a battery; the source energy continually gets dissipated entirely in the form of heat.


Applications of Heating Effect of Electric Current
CLOSE
Appliances which make use of the heating effect of electric current
Electric iron
Electric kettle
Electric cooker
Oven
Immersion heater
Nichrome wire
(heating element)
Properties of nichrome wire
it offers high resistance to the flow of current
has a high melting point

This is known as the heating effect of electric current. This effect is utilised in devices such as electric heater, electric iron etc. 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

$$P = V \; Q/t = VI$$

Or the energy supplied to the circuit by the source in time t is $P \cdot t$, that is, VIt. What happens to this energy expended by the source? 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

$$H = VIt$$

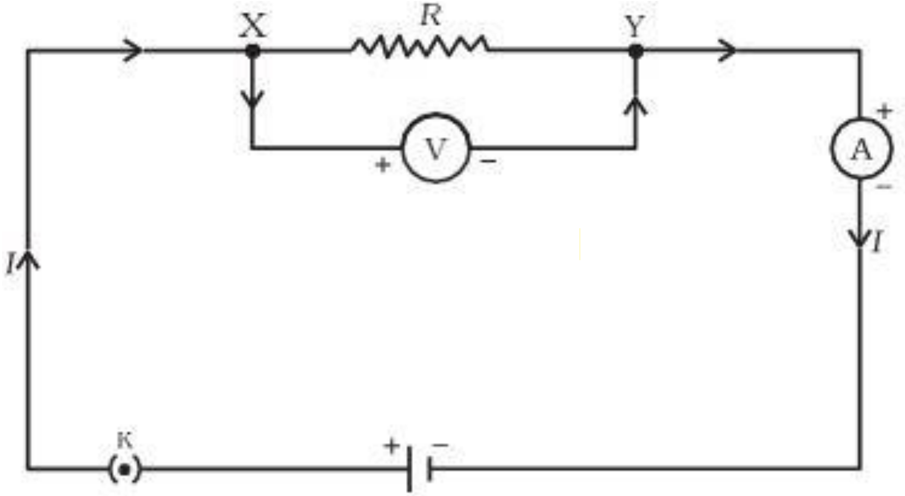
- Applying Ohm's law [Eq. (12.5)], we get

H = I2 Rt (12.21)

- 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*.



Practical Applications of Heating Effect of Electric Current

The generation of heat in a conductor is an inevitable consequence of electric current.

In many cases, it is undesirable as it converts useful electrical energy into heat.

In electric circuits, the unavoidable heating can increase the temperature of the components and alter their properties.

However, heating effect of electric current has many useful applications.

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

The electric heating is also used to produce light, as in an electric bulb. Here, the filament must retain as much of the heat generated as is possible, so that it gets very hot and emits light. It must not melt at such high temperature.

- A strong metal with high melting point such as tungsten (melting point 3380°C) is used for making bulb filaments.

- The filament should be thermally isolated as much as possible, using insulating support, etc.

- The bulbs are usually filled with chemically inactive nitrogen and argon gases to prolong the life of filament.

- Most of the power consumed by the filament appears as heat, but a small part of it is in the form of light radiated.

Another common application of Joule's heating is the fuse used in electric circuits. It protects circuits and appliances by stopping the flow of any unduly high electric current.

The fuse is placed in series with the device. It consists of a piece of wire made of a metal or an alloy of appropriate melting point, for example aluminium, copper, iron, lead etc.

If a current larger than the specified value flows through the circuit, the temperature of the fuse wire increases. This melts the fuse wire and breaks the circuit.

The fuse wire is usually encased in a cartridge of porcelain or similar material with metal ends.

The fuses used for domestic purposes are rated as 1 A, 2 A, 3 A, 5 A, 10 A, etc. For an electric iron which consumes 1 kW electric power when operated at 220 V, a current of (1000/220) A, that is, 4.54 A will flow in the circuit. In this case, a 5 A
fuse must be used.

ELECTRIC POWER

You have studied in your earlier Class that the rate of doing work is power.

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

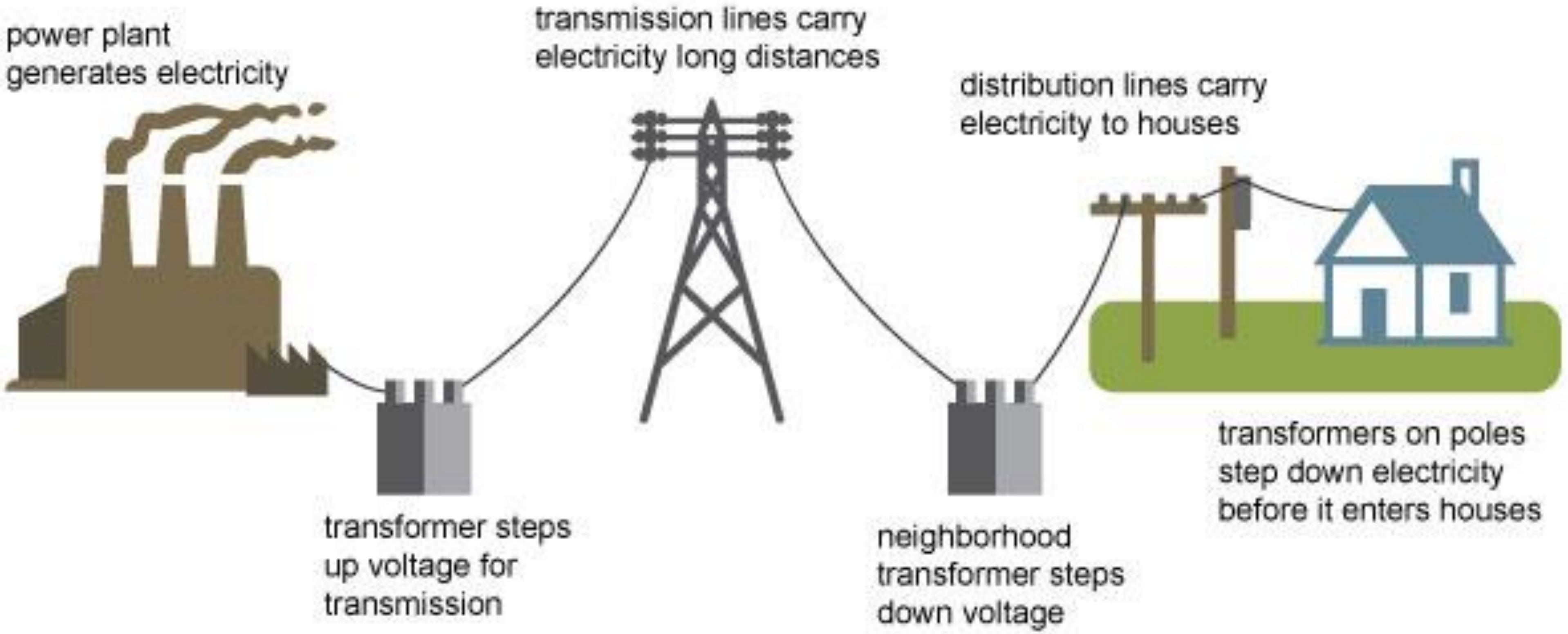
The power P is given by

$P = VI$

Or $P = I2R = V2/R$

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.

Electricity generation, transmission, and distribution



Thus,

$1\ W = 1\ volt \times 1\ ampere = 1\ V\ A$ (12.23)

- 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'.

$1\ kW\ h = 1000\ watt \times 3600\ second$

$= 3.6 \times 106\ watt\ second$

$= 3.6 \times 106\ joule\ (J)$

THANKYOU…