ELECTRICITY

Electricity is a convenient and controllable form of energy which is used widely in our homes, hospitals and industries for various purposes.

TYPES OF ELECTRIC CHARGES — There are two types of electric charges – positive and negative. Opposite charges (or unlike charges) attract each other while similar charges (or like charges) repel each other.

- The SI unit of charge is COULOMB which is equivalent to the charge contained by 6.25×10^{18} electrons.
- The amount of charge contained by a proton (or an electron) is equal to 1.6×10^{-19} Coulomb.

ELECTRIC CURRENT – is defined as the amount of electric charges flowing through a particular area in unit time (or rate of flow of electric charges). In circuits, using metallic wires, electrons constitute the flow of charges. Conventionally the direction of the current is taken as opposite to the direction of flow of electrons. i.e. from positive to negative.

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

$$I = Q/t$$

- The S.I. unit of current is AMPERE. i.e. $1 \text{ ampere} = \frac{1 \text{ coulomb}}{1 \text{ sec}}$. That means one ampere of current is generated by flow of 1 coulomb of charge in 1 sec.
- The other smaller units of current are milliampere ($1\text{ mA} = 10^{-3}\text{ A}$) or microampere ($1\,\mu\text{A} = 10^{-6}\text{ A}$).
- The current in a circuit is measured by an instrument called AMMETER. It is always connected in series in a circuit through which the current is to be measured. It has very low resistance as we want all the current to pass through it to get the correct value of current flowing in the circuit.

ELECTRIC POTENTIAL AND POTENTIAL DIFFERENCE – The electric potential (or potential) in an electric field is defined as the amount of work done in moving a unit positive charge from infinity to that point. A more common term used in electricity is potential difference.

- The difference in electric potential (or electric pressure) between two points is known as potential difference. The potential difference between two points is defined as the amount of work done in moving a unit positive charge from one point to other point.

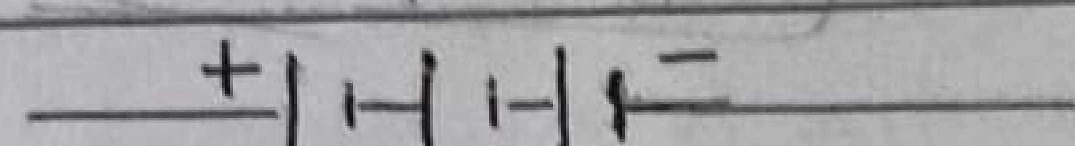
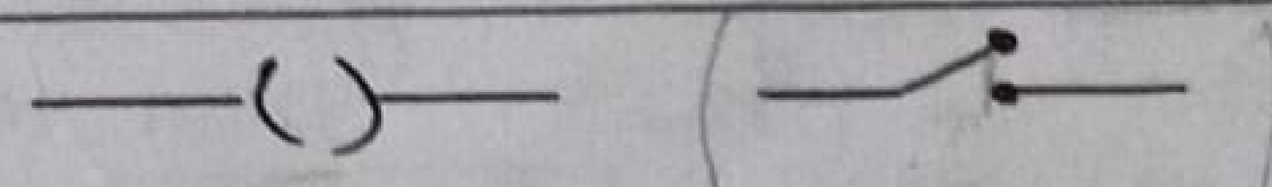
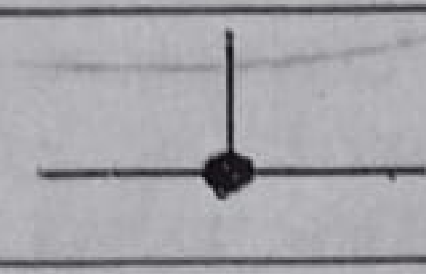
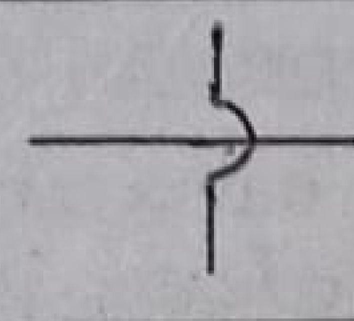
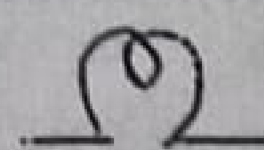
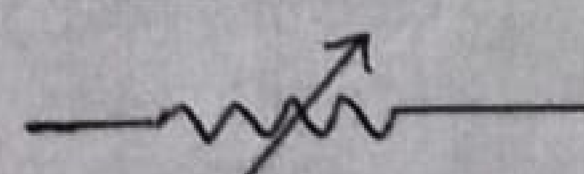
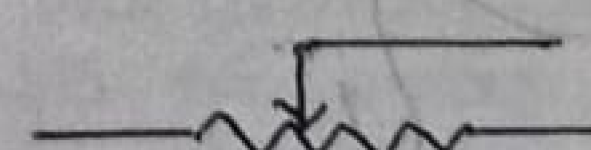
i.e. potential difference = $\frac{\text{work done}}{\text{quantity of charge moved}}$

or $$V = W/Q$$

- The SI unit of potential difference is VOLT. The potential difference between two points is said to be 1 volt if 1 Joule of work is done in moving 1 coulomb of electric charge from one point to other. Thus – $1 \text{ volt} = \frac{1 \text{ Joule}}{1 \text{ coulomb}}$ or $1\text{ V} = 1\text{ J}/1\text{ C} = 1\text{ J C}^{-1}$

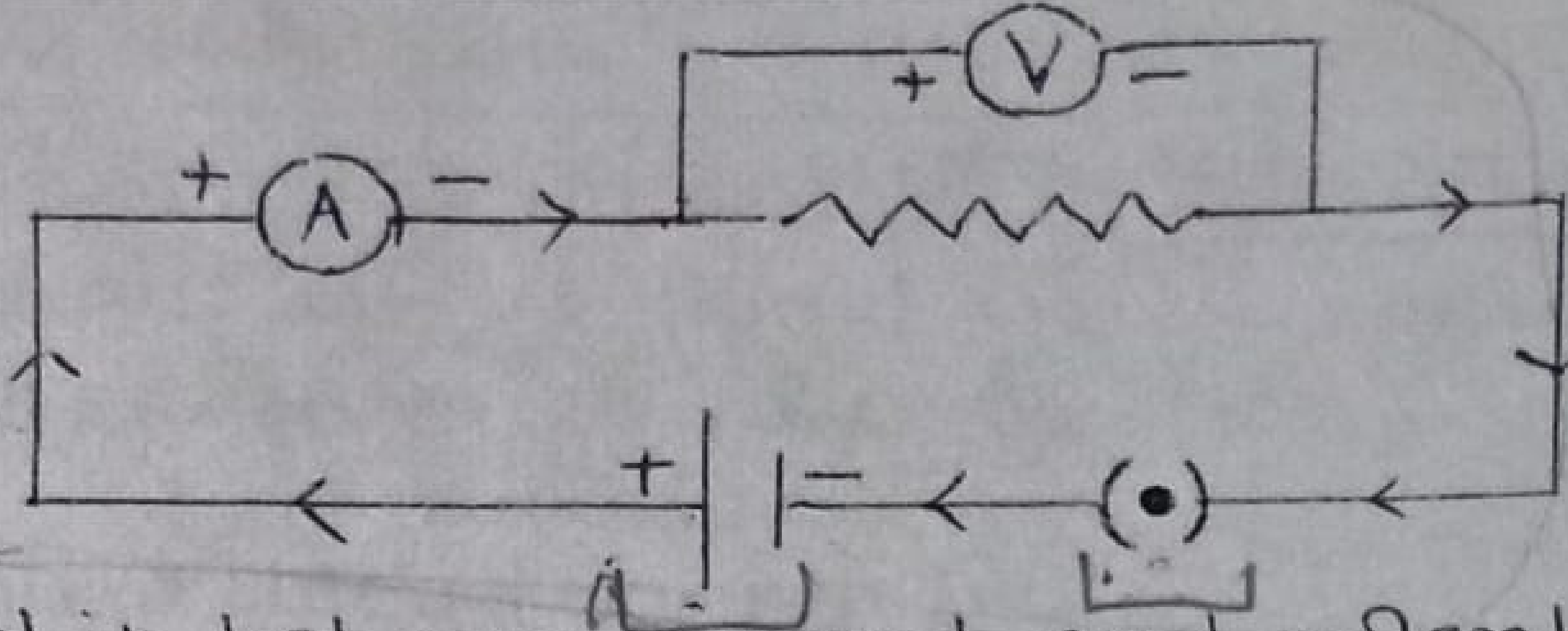
- By convention positive terminal is taken at higher potential and negative terminal at lower potential, therefore, the current will flow from positive to negative terminal (or higher potential to lower potential).
- The potential difference is measured by means of an instrument called <u>VOLTMETER</u>. [It is always connected in parallel across the points between which the potential difference is to be measured. It has high resistance so that it takes a negligible current from the circuit.]

<u>CIRCUIT DIAGRAM</u> —. Conventional symbols used to represent some of the electrical components in a circuit diagram are given below—.

S. 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.	Wire crossing without joining	
7.	An electric bulb.	
8.	Fixed resistance or resistor.	
9.	Variable resistance or rheostat.	 or 
10.	Ammeter	+ (A) −
11.	Voltmeter.	+ (V) −

- Rheostat is a variable resistance which is usually operated by a sliding contact on a long coil (made of resistance wire). It is used to change the current in a circuit without changing the voltage source like the cell or battery. It can do so by changing the resistance of the circuit.
- A diagram which shows how different components in a circuit have been connected by using electrical

symbols for the components is called a circuit diagram.
An electric circuit consisting of a cell, key, resistor, ammeter and voltmeter is shown in the figure.



OHM'S LAW - gives a relationship between current and potential difference. According to Ohm's law :- At constant temperature, the current flowing through a conductor is directly proportional to the potential difference across its ends. If I is the current flowing through a conductor and V is the potential difference across its ends, then according to Ohm's law -

$V \propto I$ or $V/I =$ constant $= R$.

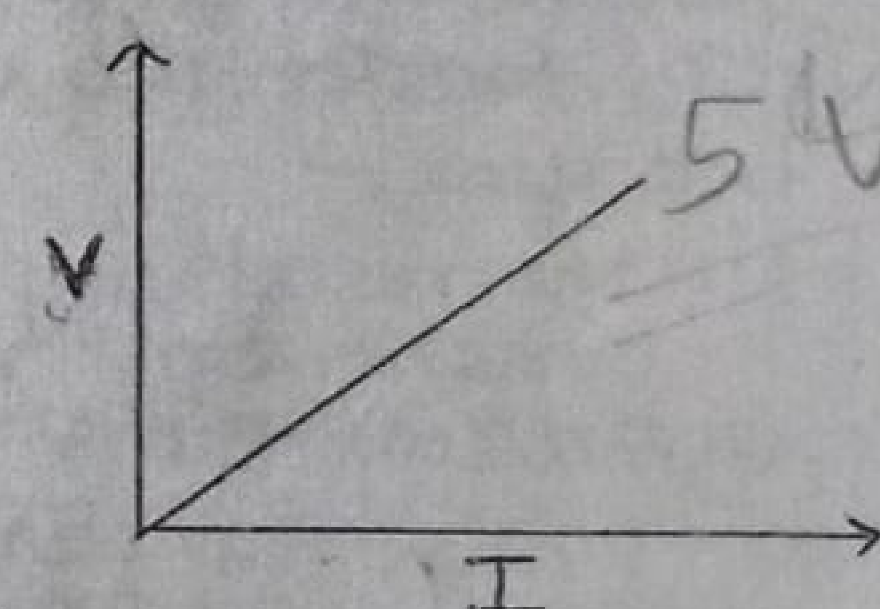
or $\boxed{V = IR}$

where R is a constant called "**RESISTANCE**" of the conductor and its value depends upon nature of metallic wire.
- The property of a conductor due to which it opposes the flow of current (or charge) through it is called resistance.
- Its SI unit is OHM, represented by the Greek letter 'Ω'.

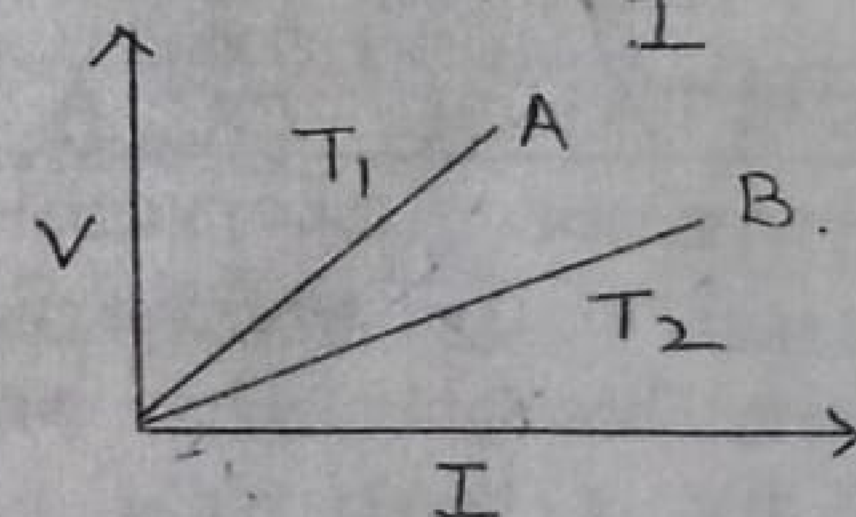
$R = \frac{V}{I}$ or $1 \text{ ohm} = \frac{1 \text{ volt}}{1 \text{ ampere}}$.

Thus, 1 ohm is the resistance of a conductor such that when a potential difference of 1 volt is applied to its ends, a current of 1 ampere flows through it.

- If a graph is plotted between the potential difference (V) and the corresponding current values (I), we get a straight line passing through the origin and the slope of V - I graph gives the resistance. Greater is the slope of V - I graph, greater is the resistance of the conductor.



- Given figure shows two straight lines A and B on the V-I graph of a conductor at two different temperatures, T_1 and T_2.



Since the resistance of conductor is more at high temperature than at low temperature and the slope of A is more than slope of line B, therefore $T_1 > T_2$.

GOOD CONDUCTORS, RESISTORS AND INSULATORS :- On the basis of their electrical resistance, all the substances can be divided into three groups -

(i) Conductors - have very low electrical resistance eg: silver, copper and aluminium.

(ii) Resistors - have comparatively high electrical resistance are called resistors. e.g. alloys like nichrome, manganin, constantan etc.

(iii) Insulators - have infinitely high resistance. It does not allow the current to flow through it. e.g. rubber, wood etc.

FACTORS ON WHICH THE RESISTANCE OF A CONDUCTOR DEPENDS

DEPENDS - Resistance of a conductor depends on the following factors -
(i) length of the conductor
(ii) area of cross section (or thickness) of the conductor.
(iii) nature of the material
(iv) temperature of the conductor.

Thus, $R \propto l$ — (i) and $R \propto 1/A$ — (ii)

On combining eq. (i) and (ii), we get -

$$R \propto l/A \quad \text{or} \quad \boxed{R = \rho\, l/A}$$

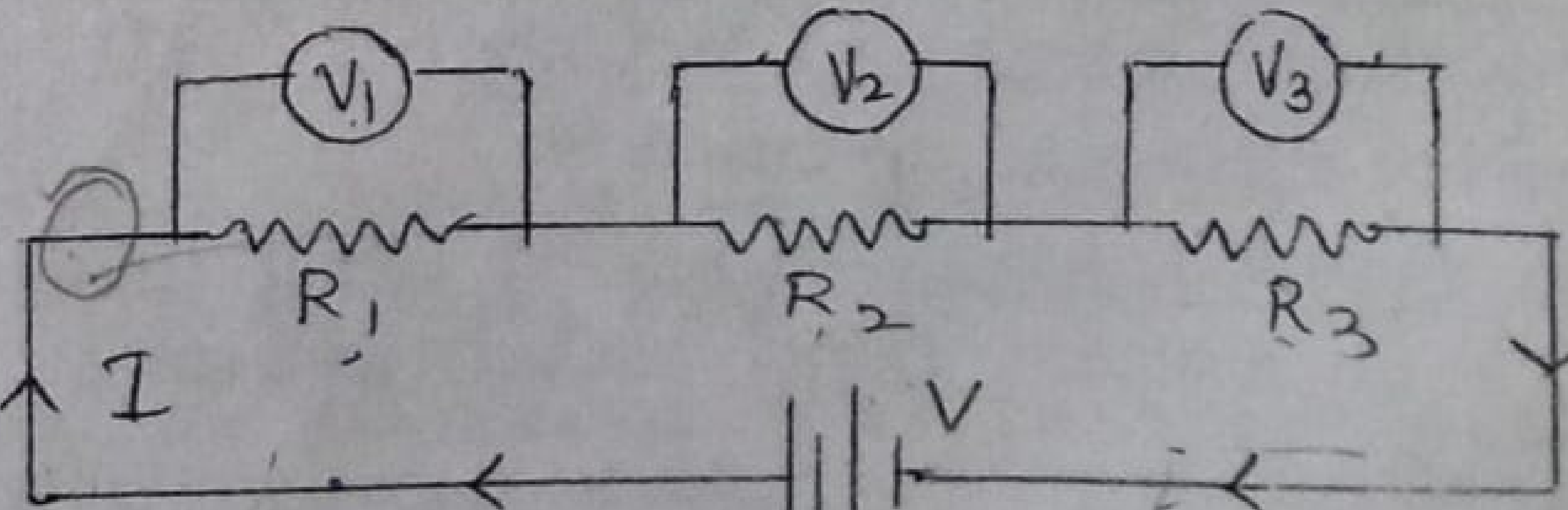
where ρ (rho) is a constant known as RESISTIVITY of the material. The SI unit of resistivity is OHM-METRE (Ω.m). It is a characteristic property of the material. The metals and alloys have very low resistivity in the range of $10^{-8}\,\Omega m$ to $10^{-6}\,\Omega m$. and they are good conductors of electricity. Insulators have high resistivity of the order of 10^{12} to $10^{17}\,\Omega m$.

- Both the resistance and resistivity vary with temperature. For most of the metals resistance and resistivity increases with increase in temperature.
- The heating element of electrical heating appliances such as electric iron, toaster etc are made of an alloy rather than a pure metal because -
  (i) the resistivity of an alloy is much higher than that of its constituent metals.
  (ii) alloy does not undergo oxidation (or burn) easily even at high temperature

RESISTANCE OF A SYSTEM OF RESISTORS

RESISTANCE OF A SYSTEM OF RESISTORS - Apart from potential difference, current in a circuit depends on the resistance of circuit. In electrical appliances, combination of resistors are used to get the required current in the circuit. The resistances can be combined in two ways -
(i) in series. (ii) in parallel

(i) Resistances in series - In series, resistances are connected end to end consecutively. and this type of combination is used when we want to increase the total resistance.



- In series connections, same current flows through each resistance (which is equal to the current flowing in the whole circuit), while potential difference across each resistance will be different (which depends on the value of resistance). But the total potential difference across the ends of all the resistance in series is equal to the voltage of the battery.

i.e. $V = V_1 + V_2 + V_3$

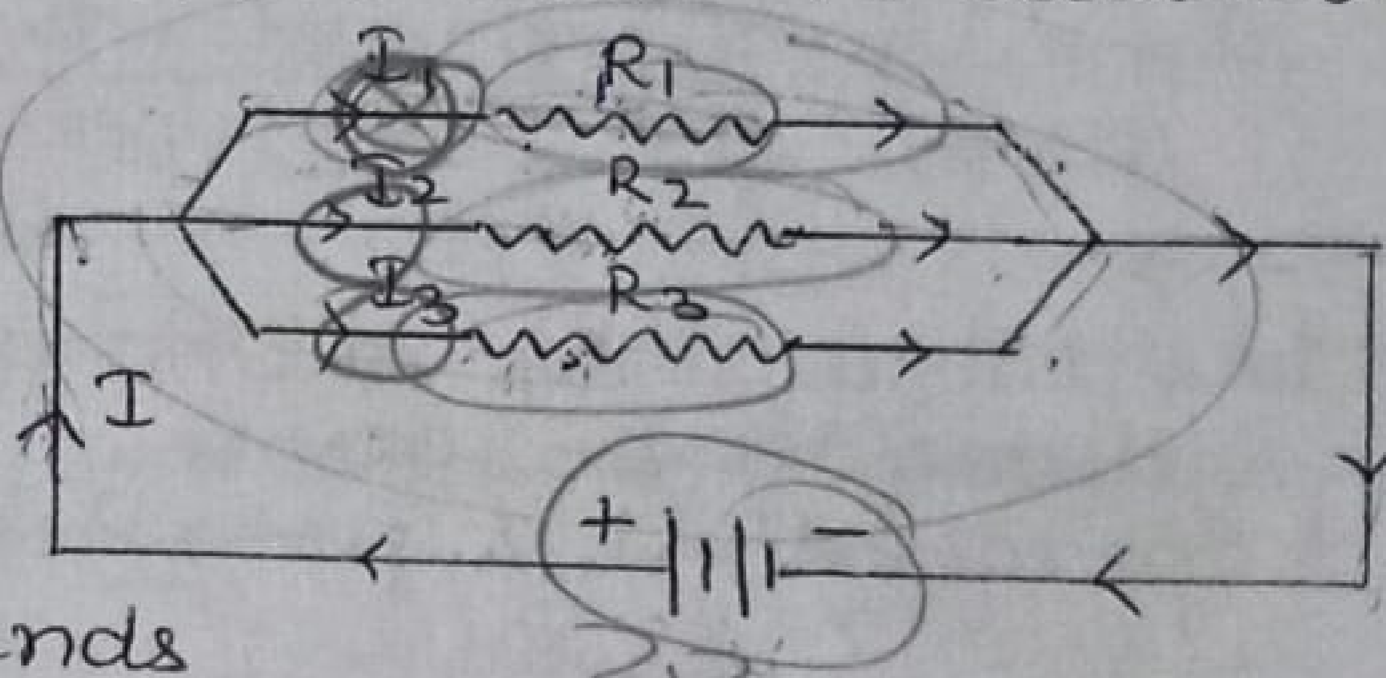
If the current through the circuit is I and R is the equivalent resistance of the combination, then –

$IR = IR_1 + IR_2 + IR_3$ or $IR = I(R_1 + R_2 + R_3)$

or $\boxed{R = R_1 + R_2 + R_3}$

Thus in series, the resistance of the combination R_s equals the sum of their individual resistances and is thus greater than any individual resistance.

(ii) Resistances in parallel – In parallel, the two or more resistances are connected between the same two points and this type of combination is done when we want to decrease the total resistance.



– In parallel combination, the potential difference across each resistance is same which is equal to the voltage of the battery applied. The current flowing through each resistor will be different (which depends on the value of resistance) but the sum of the currents flowing through all the resistances is equal to the total current flowing in the circuit i.e. $I = I_1 + I_2 + I_3$.

or $V/R = V/R_1 + V/R_2 + V/R_3$ or $V/R = V(1/R_1 + 1/R_2 + 1/R_3)$

or $$\boxed{\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

Thus in parallel, 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. and the value of equivalent resistance will be less than the smallest individual resistance.

DOMESTIC ELECTRIC CIRCUITS : SERIES OR PARALLEL – Due to the following reasons, parallel circuits are preferred over series circuits for domestic wiring –.

Disadvantage of series circuits in domestic wiring –

(i) If one appliance stops working due to some defect, then all other appliances also stop working (because the whole circuit is broken).

(ii) all the electrical appliances have only one switch due to which they can not be turned on or off separately.

(iii) all the appliances do not get the same voltage (220 V) as that of the power supply line. (because the voltage is shared by all the appliances)

(iv) In series connection, the overall resistance of the circuit increases, due to which the current from the power supply is low.

Advantages of parallel circuits in domestic wiring –

(i) If one appliance stops working due to some defect, then all other appliances keep working normally.

(ii) Each electrical appliance has its own switch due to which it can be turned on or off independently without affecting other appliances.
(iii) each electrical appliance get the same voltage (220V) as that of the power supply line.
(iv) In parallel connection, the overall resistance of the household circuit is reduced due to which the current from the power supply is high.

ELECTRIC POWER – is defined as the rate at which electrical work is done or the rate at which electrical energy is consumed. i.e.

$$P = \frac{W}{t} = \frac{V \times Q}{t} = \frac{V \times I \times t}{t} = VI$$

or $$\boxed{P = VI = I^2 R = V^2/R}$$ *

- The SI unit of electric power is watt. It is the power consumed by a device that carries 1 ampere of the current when operated at a potential difference of 1 volt. Thus —

$$1 \text{ watt} = 1 \text{ volt} \times 1 \text{ ampere}.$$

- The other larger units of electric power are kilowatt and megawatt. and $1 \text{ kw} = 10^3$ watts.

$1 \text{ MW} = 10^6$ watts.

POWER – VOLTAGE RATING OF ELECTRICAL APPLIANCES – Every electrical appliance has a label or engraved plate on it which tells us the voltage (to be applied) and the electric power consumed by it. For example on an electric bulb 100W – 220V is written that means this bulb has a power consumption of 100W (or it will consume 100 J of energy in one second) if it is used at 220V. From power rating, we can also find the current drawn by it as $P = V \times I$.

ELECTRICAL ENERGY – We know that –

Electrical energy = Power × time.

or $$\boxed{E = P \times t}$$

Thus electrical energy consumed by an electrical appliance depends on two things – (i) power rating of the appliance.
(ii) time for which appliance is used.

- The SI unit of electrical energy is Joules while commercial unit is kilowatt hour (kWh) commonly known as "UNIT"

$$1 \text{ kWh} = 1 \text{ kw} \times 1 \text{ hr} = 1000 \text{ W} \times 3600 \text{ sec}$$
$$= 3.6 \times 10^6 \text{ watt} \times \text{sec}$$
$$= 3.6 \times 10^6 \text{ Joules}$$

* As power is inversely proportional to resistance. therefore, the resistance of high power device is smaller than the low power ones. For example, the resistance of 100W (220V) bulb is smaller than that of a 60W (220V) bulb. ($\because P = V^2/R$)

HEATING EFFECT OF ELECTRIC CURRENT – When an electric current is passed through a high resistance wire, it becomes very hot and produces heat. This is called heating effect of current. Thus electrical energy is converted into heat energy.

– It should be noted that only and only electrical heating appliance converts most of the electrical energy into heat energy and not all the electrical appliances. For example when electric current is passed through a fan, then most of the electrical energy is converted into mechanical energy (or used up in turning the blades of a fan), only a small amount of electrical energy is converted into heat energy. Due to this it becomes slightly warm when run continuously for a long time. On the other hand, when current is passed through an electrical heating appliance such as electric heater, geyser, immersion rod etc, then almost all the electrical energy gets converted into heat energy due to the high resistance of heating coil or heating element.

– According to Joule's law of heating, the heat produced in a wire is directly proportional to :–

(i) square of current

(ii) resistance of wire.

(iii) time for which current is passed.

i.e. $$H = I^2 R t$$

In practical situations, when an electrical appliance is connected to a known voltage source, the above relation is used after calculating the current through it, using the relation $I = V/R$.

PRACTICAL APPLICATIONS OF HEATING EFFECT OF ELECTRIC CURRENT. – (i) All electrical heating appliances are based on heating effect of current. These appliances have coil of high resistance made of nichrome alloy. Which produce large amount of heat. In connecting wire (which are made up of copper) neiligible amount of heat is produced due to its low resistance.

(ii) Heating effect of current is also utilized in electric bulb to produce light. When an electric current is passed through a very thin, high resistance tungsten filament of bulb, the filament becomes white-hot and emits light.

– Tungsten metal is used for making filaments as it has a very high melting point (3380°C). Due to high melting point it remains white-hot without melting away.

– The bulbs are filled with chemically inactive nitrogen and argon gases to prevent the oxidation of filament so as to prolong its life.

(iii) Another common application of heating effect of current is electric fuse. It protects the circuits and appliances by stopping the flow of any unduly high current. A fuse consists of a short piece of wire of a metal or an alloy of suitable melting point which melts if a current larger than specified value flows through the circuit and thus breaks the circuit. It is always placed in a series with the device.

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