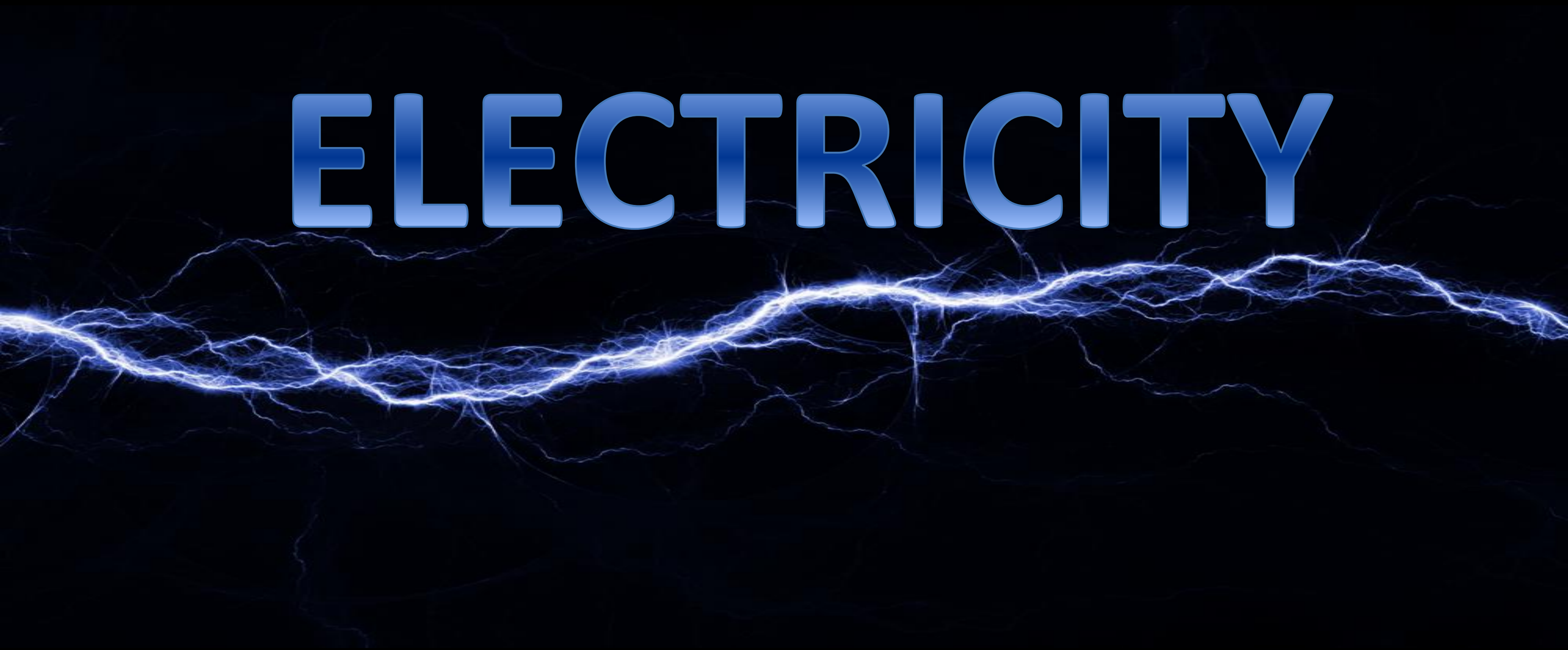
CHAPTER 12

ELECTRICITY



Acknowledgment

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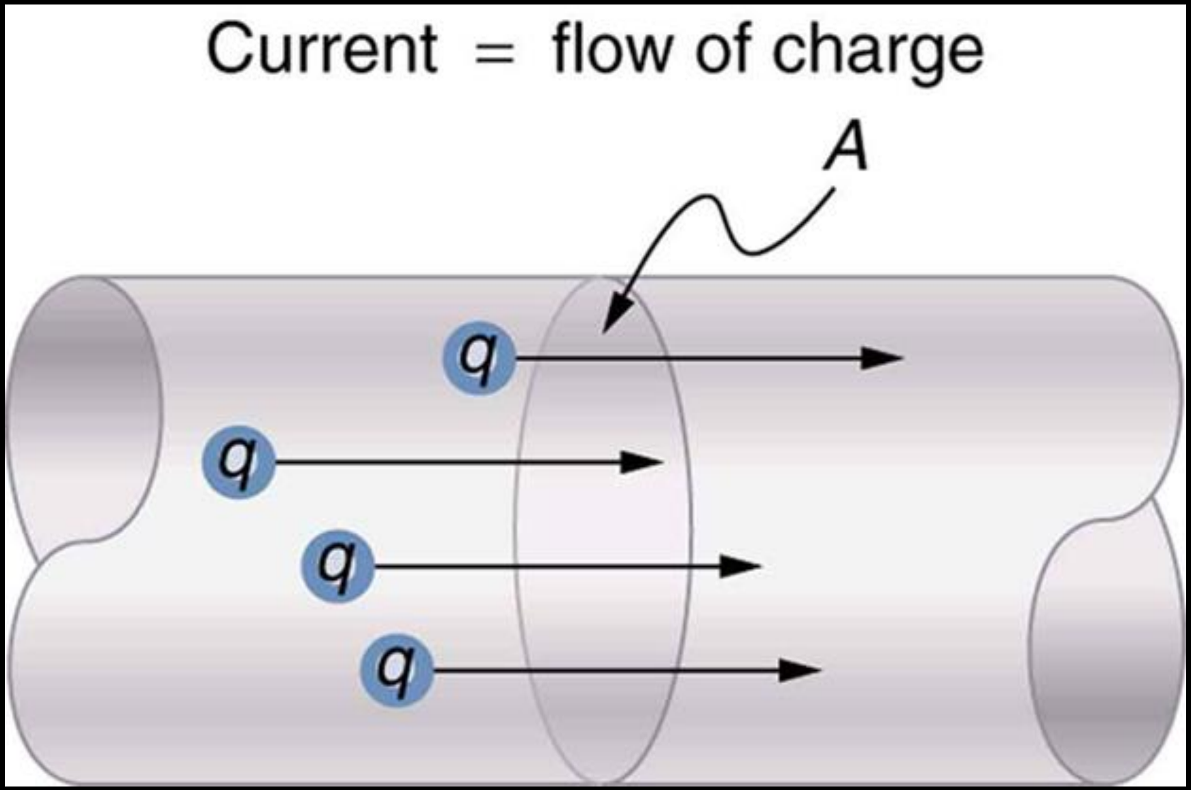
Contents

Electric current

Electric current is defined as rate of flow of charges.



Conductors

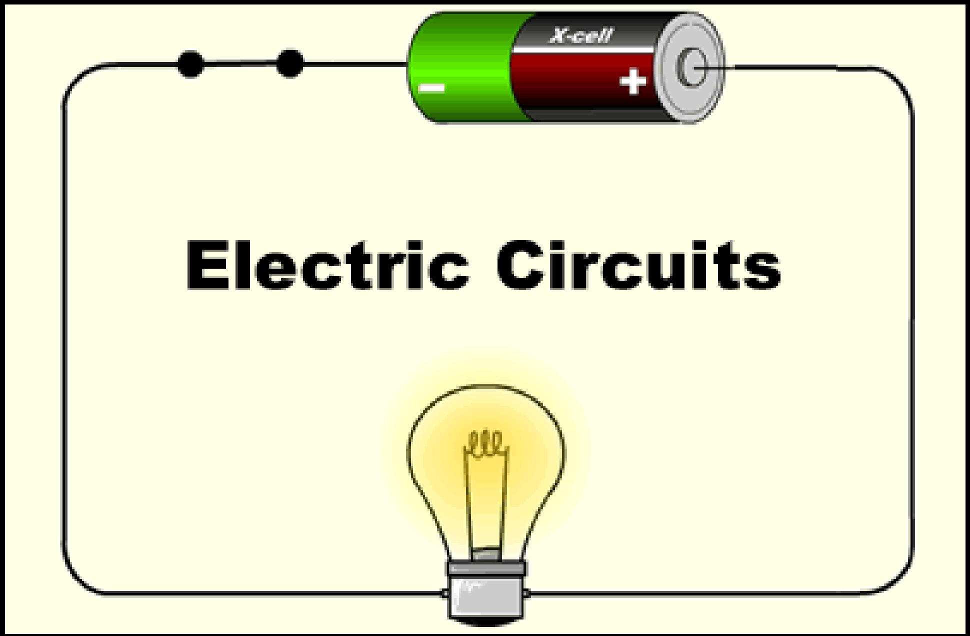
The substances through which electricity can flow are called conductors.

Ex: Metals like Silver, copper, aluminium, alloys such as nichrome, carbon in the form of graphite, etc.

Conductors

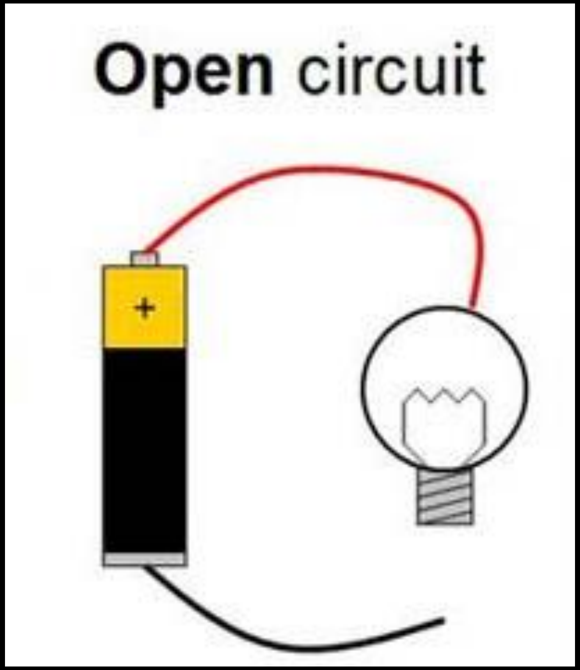
Electric circuit

A closed and continuous path along which an electric current flows is called an electric circuit.



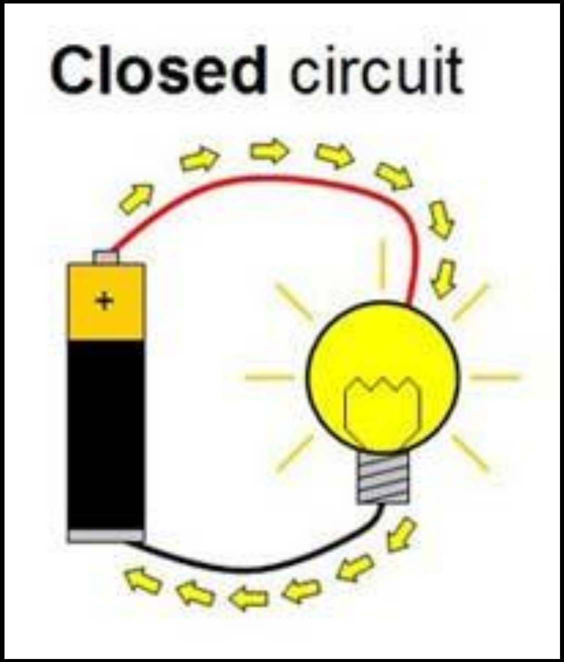
Open circuit

An electric circuit through which no current flows is called an open circuit.



Closed circuit

An electric circuit through which current flows continuously is called an closed circuit.



Insulator

The substances through which electricity cannot flow are called insulators.

Ex: Glass, ebonite, rubber, most plastics, paper, dry wood, cotton, mica, Bakelite, porcelain, dry air.

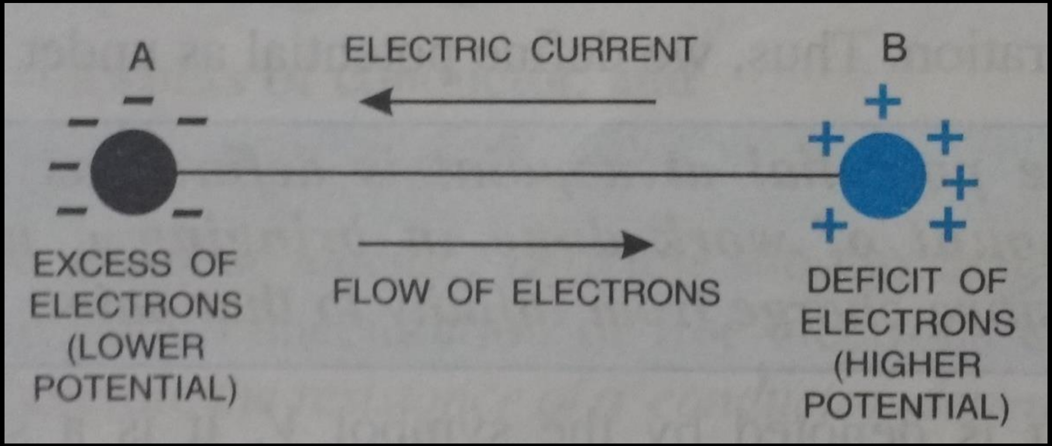
Insulator

How is electric current expressed ?

Electric current is expressed by the amount of charge flowing through a particular area in unit time.

Conventional flow of electric energy

The electric current flows from a region of higher potential to a region of lower potential. That is in a direction opposite to the direction of flow of electrons.

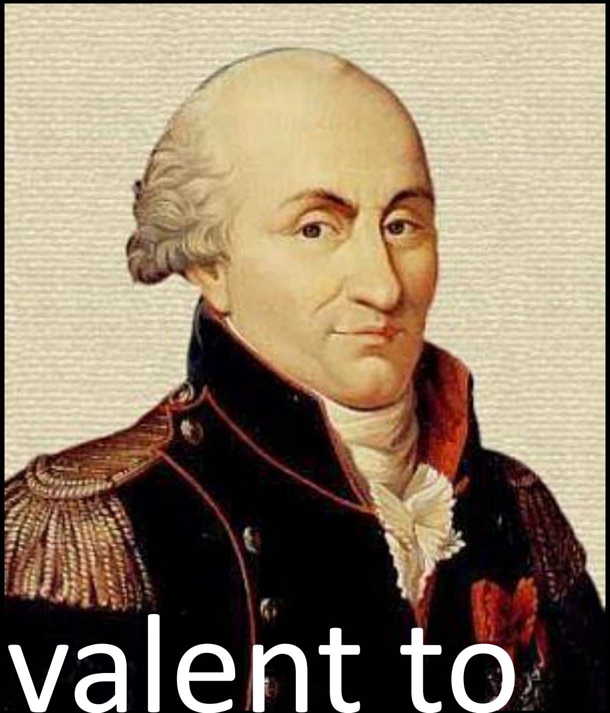


Formula for current through a cross section

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

Where the Q is the net charge, t is time and I is the current.

SI unit of charge



coulomb (C)

One coulomb is equivalent to the charge contained in nearly 6×10^{18} electrons.

Charge of an electron

Electron has a negative charge of 1.6×10^{-19} C.

Calculate the number of electrons constituting one coulomb of charge.

1 electron = 1.6×10^{-19}C .

x electrons = 1 C

$$x = \frac{1}{1.6x10^{-19}} = \frac{10^{19}}{1.6} = \frac{10}{1.6}x10^{18}$$

6.25×10^{18} electrons are present in one coulomb of charge.

Unit of electric current

Electric current is expressed by ampere (A).

Ampere

The electric current flowing through a conductor is said to be one ampere when one coulomb of charge flows through a conductor in one second.

Ampere

$$1\,ampere = \frac{1\,coulomb}{1\,\sec ond}$$

Other units of electric current.

Milliampere (1mA = 10^{-3} ampere)

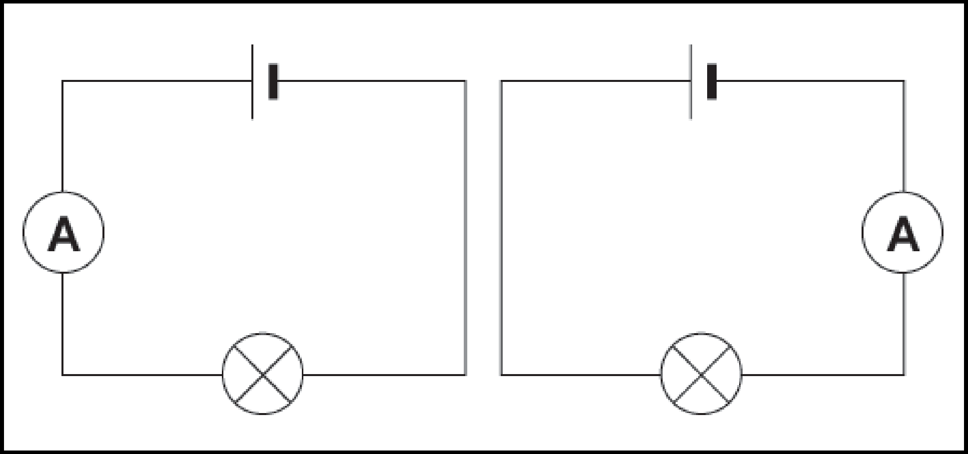
Microampere (1mA=10^{-6} ampere)

Ammeter

The instrument used to measure current in a circuit is called ammeter.

How is an ammeter connected in a circuit?

An ammeter is always connected in series in a circuit through which the current is to be measured.



Why should an ammeter have a very low resistance?

Since the entire current passes through the ammeter, It should not change the value of current flowing in the circuit.

Electric potential

The electric potential at a point in an electric field is defined as the work done in moving a unit positive charge from infinity to that point.

SI Unit of Electric potential

The SI unit of electric potential is volt.

Potential difference

The potential difference between two points in an electric circuit is defined as the amount of work done in moving a unit positive charge from one point to the other point.

Potential difference

$$\text{Potential difference} = \frac{\text{Work done}}{\text{Charge moved}}$$

$$V = \frac{W}{Q}$$

One volt

If 1 Joule of work is required to move a charge of 1 coulomb from one point to another, then the potential difference between the two points is 1 *V*.

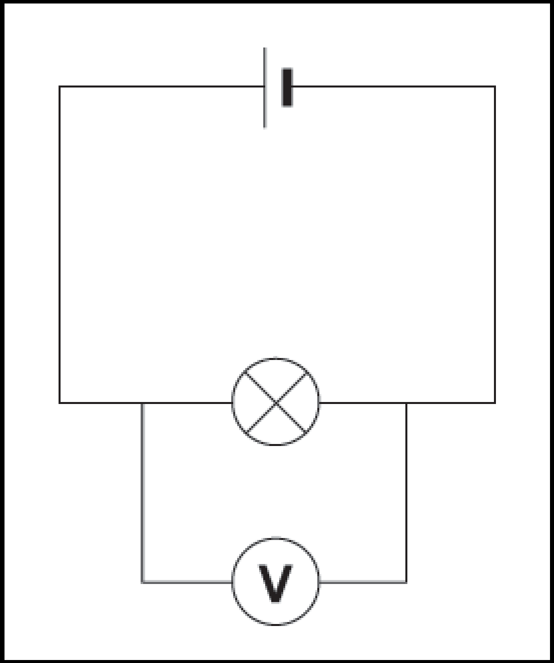
$$1\ \text{volt} = \frac{1\ \text{joule}}{1\ \text{coloumb}}$$

Voltmeter

A Voltmeter is a device used to measure the potential difference.

How is a voltmeter connected in a circuit?

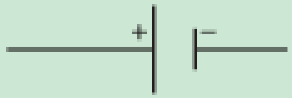
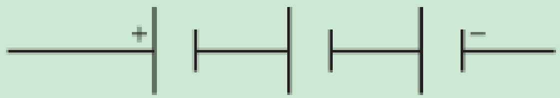
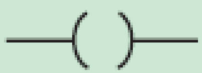
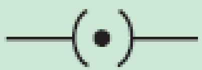
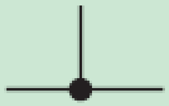
A voltmeter is always connected in parallel across the points where the potential difference is to be measured.



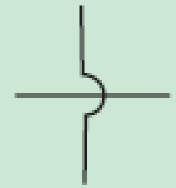
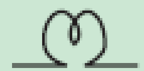
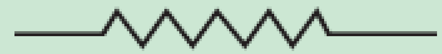
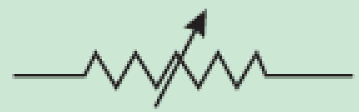
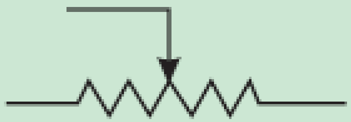
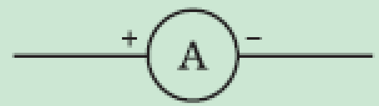
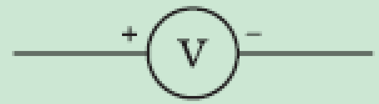
Why should a voltmeter have a high resistance?

A voltmeter should have a high resistance so that it draws a negligible current from the circuit.

Symbols used in electric circuit

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	

Symbols used in electric circuit

Sl. No.	Components	Symbols
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

At constant temperature, the current flowing through a conductor is directly proportional to the potential difference across its ends.

Mathematical form of Ohm's Law

$$V = R \times I$$

Where V = potential difference

I = current

R = resistance

Resistance

Resistance is defined as the ratio of the potential difference across the conductor to the current flowing though the conductor.

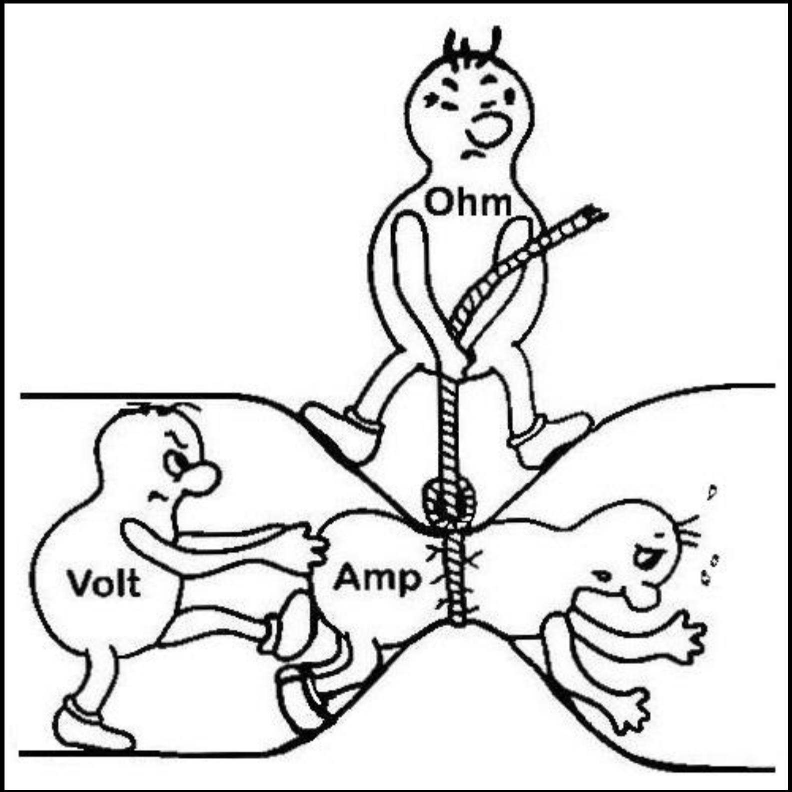
OR

Resistance is the property of a conductor to resist the flow of charges through it.

Resistance

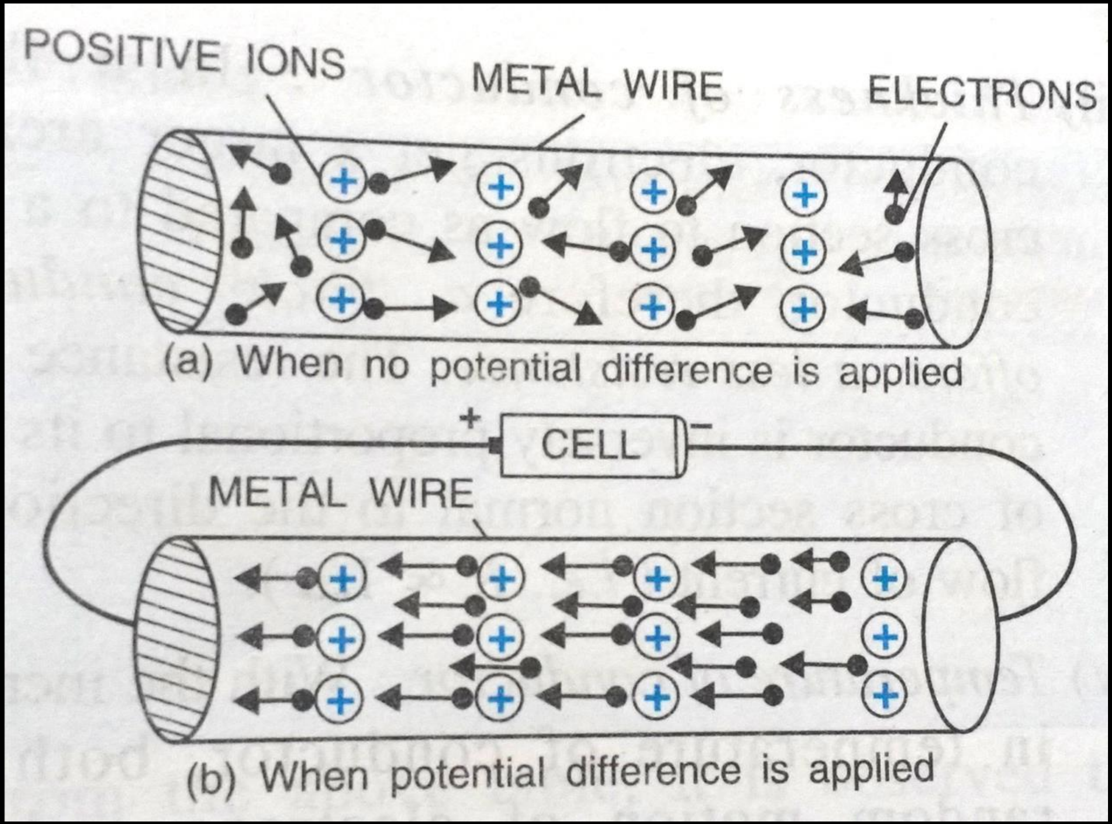
$$R = \frac{\text{Potential difference}}{\text{Current}}$$

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



Cause of Resistance

When free electrons drift inside a conductor, they frequently collide with its positive ions or atoms. The motion of the electrons is opposed during the collisions.



SI unit of Resistance

The SI unit of resistance is ohm denoted by the symbol Ω

1 Ohm

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 ohm.

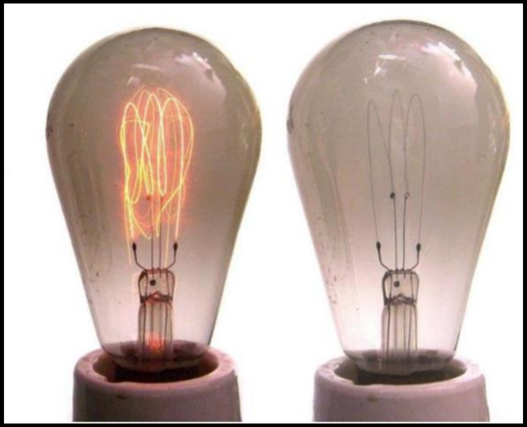
$$1\,\text{ohm} = \frac{1\,\text{volt}}{1\,\text{ampere}}$$

Relation between resistance and current

The current through a resistor is inversely proportional to its resistance.

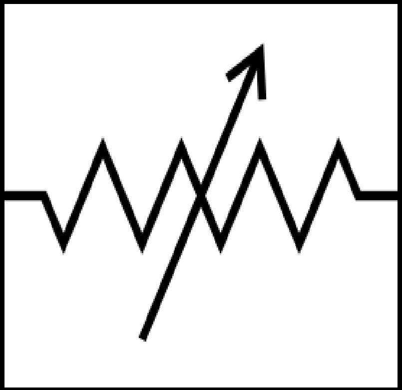
Why tungsten is used almost exclusively for filament of electric lamps?

The melting point and resistivity of tungsten are very high. It does not burn readily at a high temperature. The electric lamps glow at very high temperatures. Hence, tungsten is mainly used as heating element of electric bulbs.



Rheostat

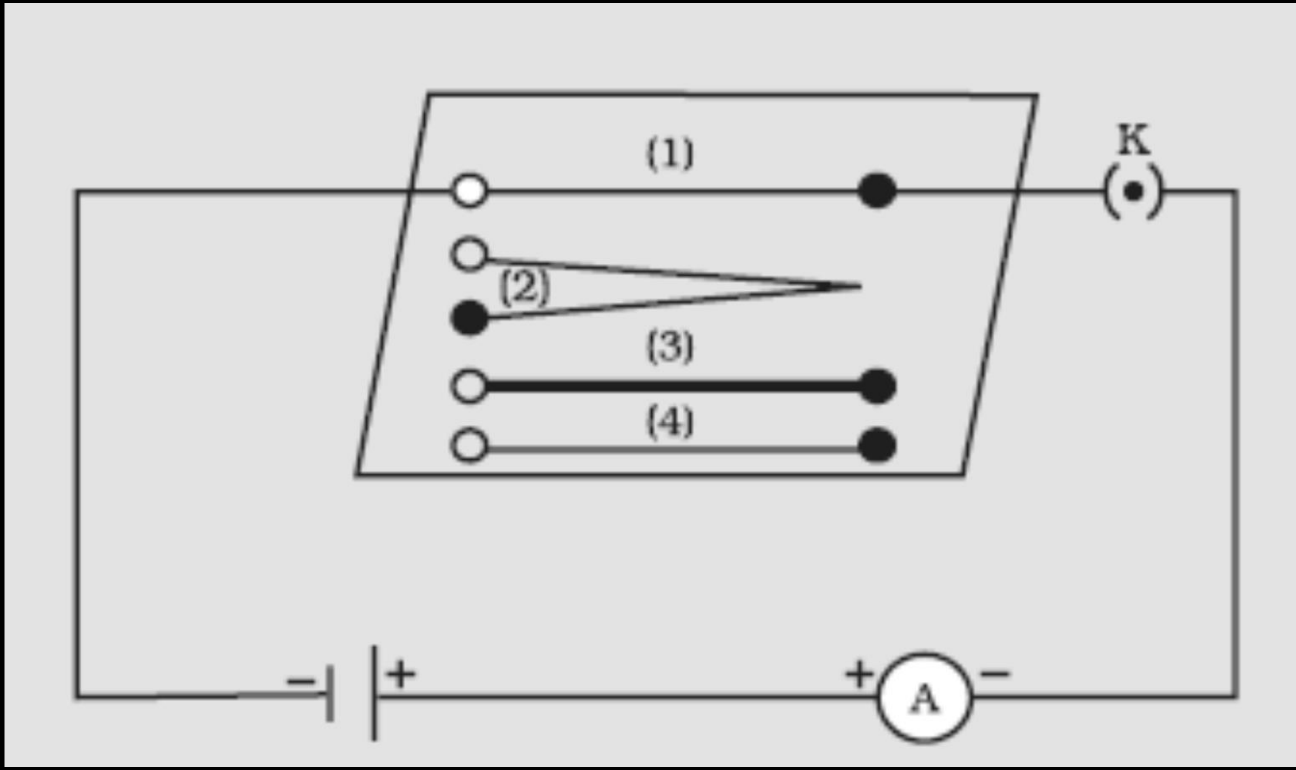
A device used to change the magnitude of the current by changing the length of the resistance wire inserted into the circuit called variable resistance or rheostat.



Difference between resistance and Resistor

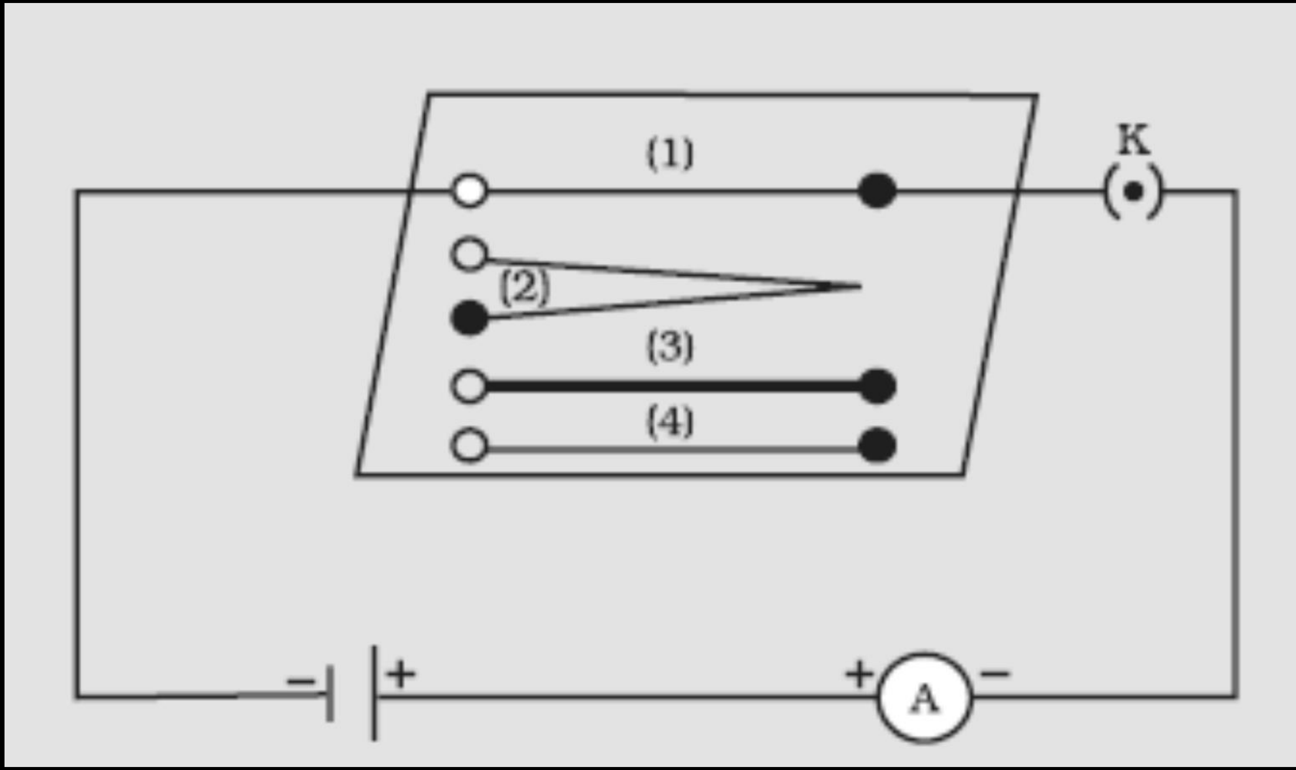
Resistance	Resistor
The property by virtue of which a material opposes the flow of current through it is called resistance.	Any material which has some resistance is called a resistor.

Activity



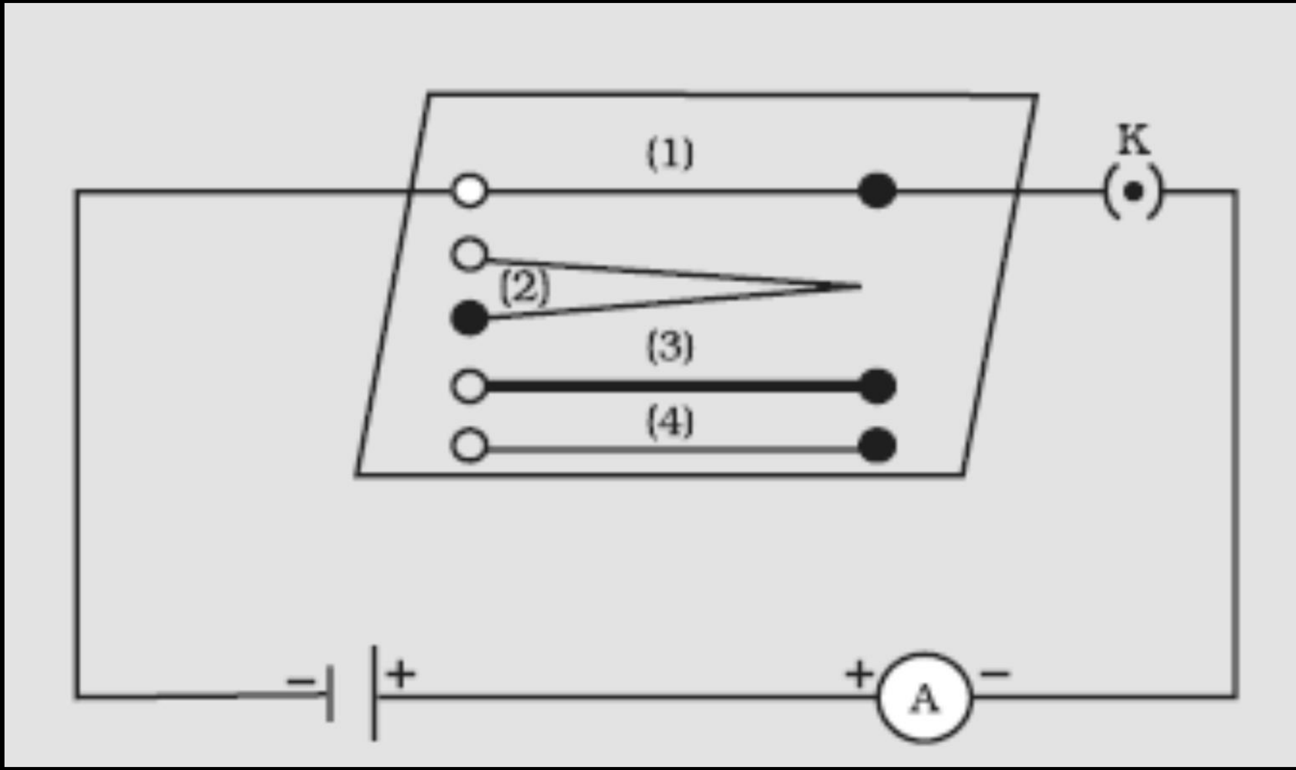
When the length of the wire is doubled, the ammeter reading decreases to one-half its initial value.

Activity



When we use a thicker wire of the same material and of the same length, the current in the circuit increases.

Activity



When we use copper wire of similar dimensions in place of the nichrome wire, the current in the circuit increases.

Factors on which resistance of a conductor depends

The resistance of a conductor depends:

1) On its length
2) On its area of cross-section
3) On the nature of its material
4) Temperature of the conductor

Resistance of a conductor depends on length

Resistance of a conductor is directly proportional to its length.

$$R \propto L$$

Resistance of a conductor depends on area of cross-section

Resistance of a conductor is inversely proportional to its area of cross-section.

$$R \; \alpha \; \frac{1}{A}$$

Resistance of a conductor depends on nature of the material

Resistance also depends on the nature of the material of which the conductor is made. The resistance of a copper wire is much less than that of a nichrome wire of same length and area of cross-section.

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

Resistivity

Resistivity is defined as the resistance offered by a cube of material of side 1m when current flows perpendicular to its opposite faces.

$$\rho = \frac{R \times A}{L}$$

SI unit of Resistivity

SI unit of resistivity is ohm-meter (Ω m)

Difference between resistance & Resistivity

Resistance	Resistivity
Electrical resistance of a conductor changes with change in length or area of cross-section of the conductor.	Electrical resistivity of a conductor remains constant at a particular temperature.

Classification of solids on the basis of resistivity

On the basis of resistivity values, solids can be classified into:

1) Conductors
2) Insulators
3) Semi conductors

Conductors

Metals and their alloys have low resistivity in the range of $10^{-8}\Omega m$ to $10^{-6}\Omega m$. These are good conductors of electricity. They offer low resistance to the flow of current. Copper & aluminium have lowest resistivities.

Insulators

Insulators are substances which have large resistivities, more than $10^4 \Omega m$. Insulators like glass and rubber have high resistivities in the range of $10^{12} \Omega m$ to $10^{17} \Omega m$.

Semiconductors

Semiconductors are the substances whose resistivities lie between those of conductors and insulators i.e. between 10^{-6} to $10^{-4} \Omega m$.

Ex: Germanium and silicon.

A wire of resistivity ρ is stretched to three times its length. What will be its new resistivity?

Resistivity remains unchanged as it does not depend on length. It depends on the nature of the material of the wire.

Why do we use copper and aluminium wires for transmission of electric current?

copper and aluminium have low resistivity or high conductivity.

Resistivity

- Silver has the lowest resistivity (resistivity = 1.60 x 10^{-8} ohm-metre)
- The resistivity of an alloy is generally higher than that of pure metals which from the alloy.
- The resistivity of an alloy like constantan does not change with its temperature.

Why are coils of electric toasters and electric irons made of an alloy rather than a pure metal?

The coils of electric toaster and electric iron are made of alloys instead of pure metal due to:

- Alloys have higher resistivity than that of their constituent metals.
- Alloys do not oxidize (or burn) readily at high temperatures.

Need for combination of resistances in an electric circuit

In order to obtain a desired value of current in an electrical circuit, a number of resistances have to be used. Resistances can be combined together in the following three ways:

i) series combination

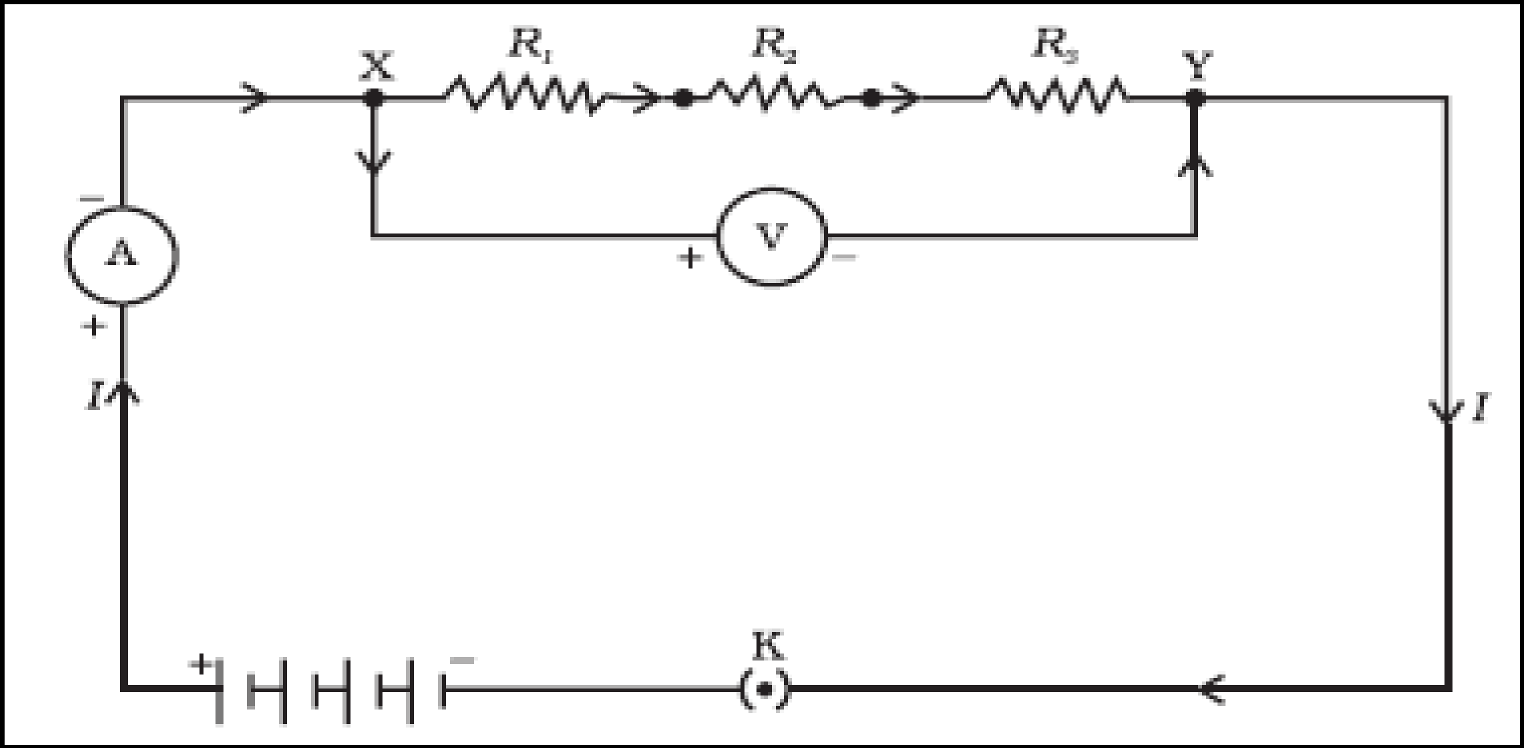
ii) parallel combination

iii) mixed combination

Resistances in series

- The current has a single path for its flow. Hence the same current passes through each resistor and so the potential difference across any resistor is directly proportional to its resistance.
- The potential difference across the entire circuit is equal to the sum of the potential differences across the individual resistors.

Resistances in series



$$V=V_1+V_2+V_3$$

The resistance of the combination Rs equals the sum of their individual resistances, R1, R2, R3, and is thus greater than any individual resistance.

$R_s=R_1 + R_2 +R_3$

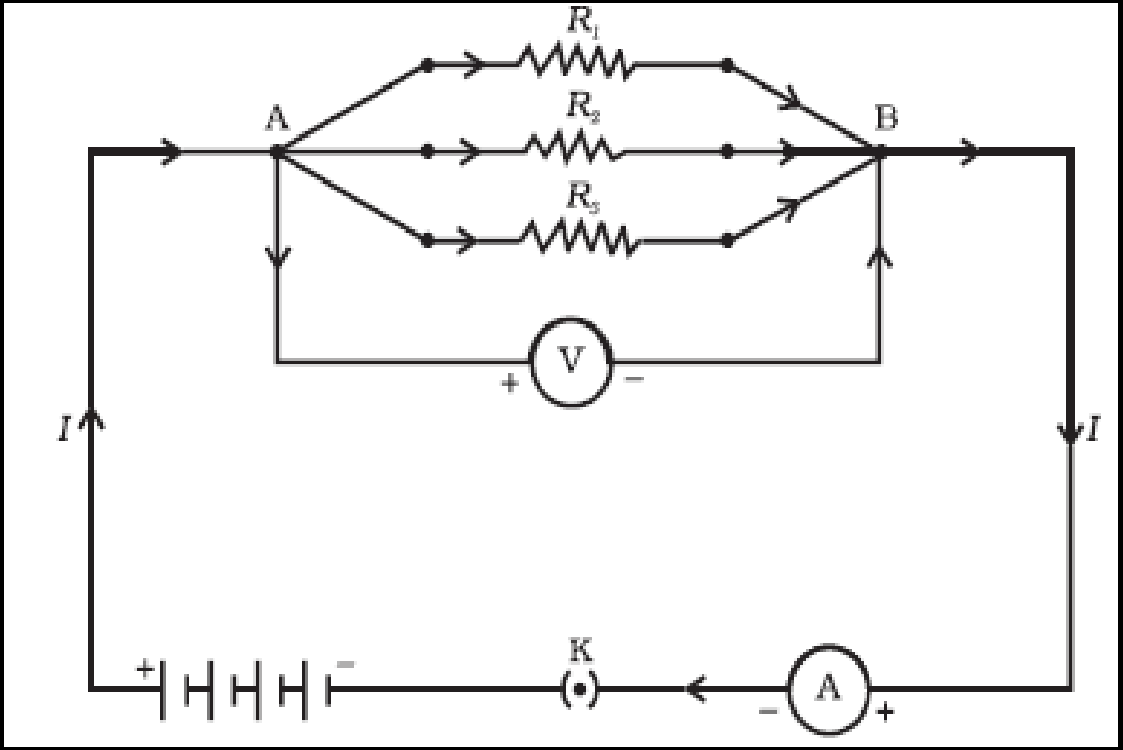
Resistances in parallel

- The potential difference across each resistance is the same which is equal to the potential difference across the terminals of the battery.
- The current in a resistor is inversely proportional to its resistance. The sum of the currents I_1, I_2, I_3 … etc in the separate branches of the parallel circuit is equal to the current I drawn from the source.

$$I = I_1 + I_2 + I_3$$

Resistances in parallel

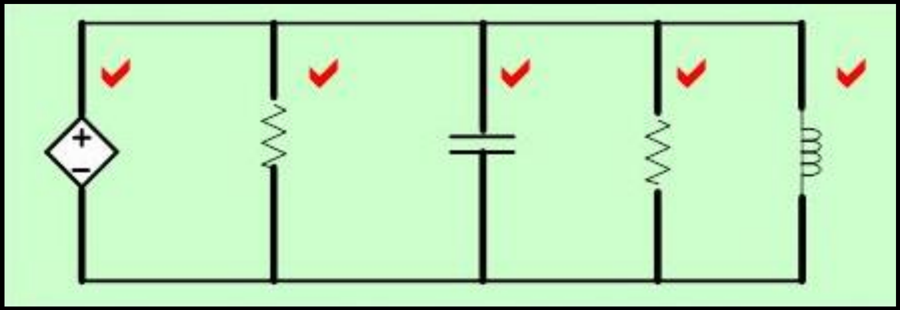
- The reciprocal of the equivalent resistance of a group of resistances joined in parallel is equal to the sum of the reciprocals of the individual resistances.



$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Advantage of connecting electrical devices in parallel

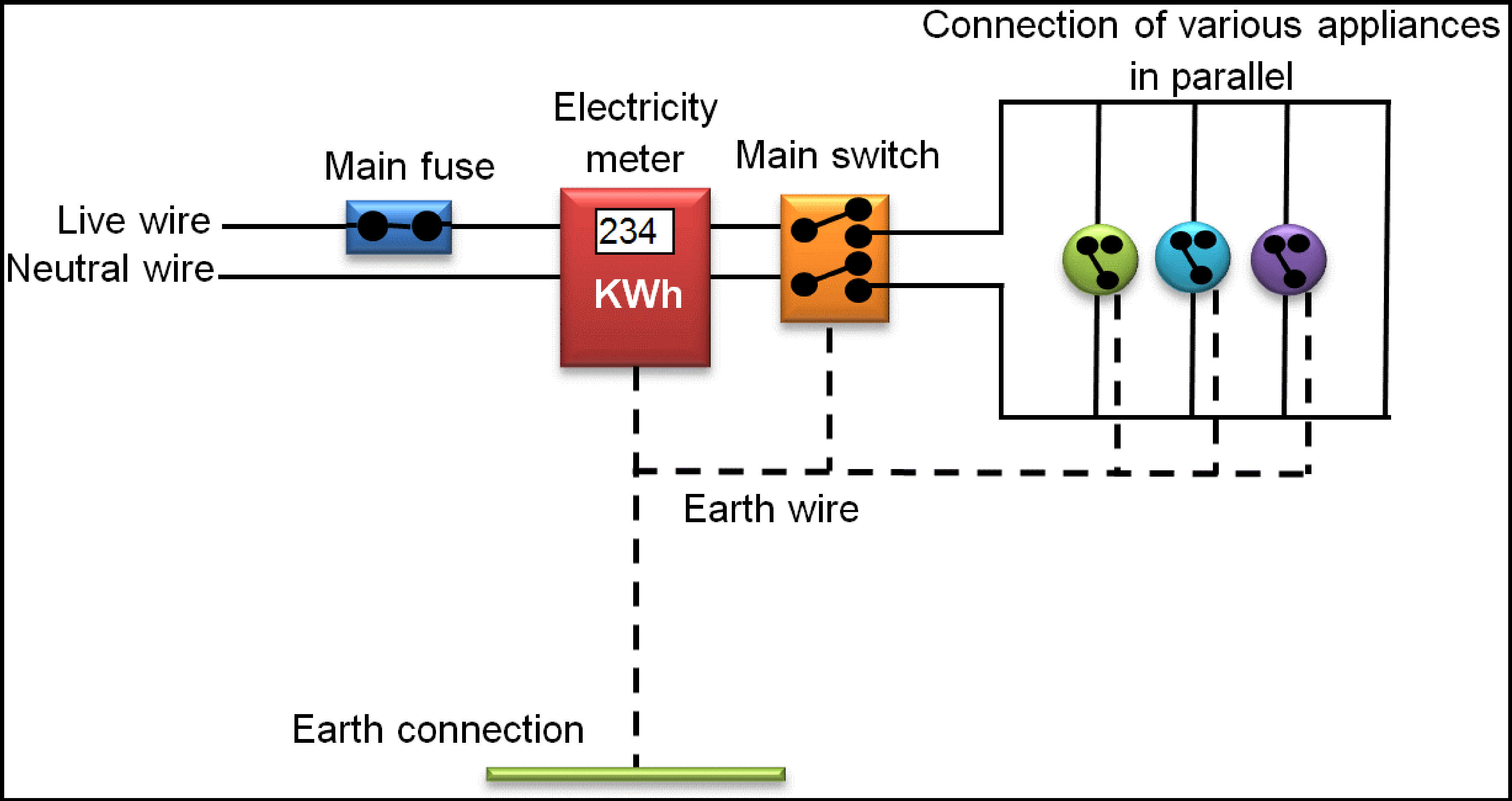
- There is no division of voltage among the appliances when connected in parallel.
- The potential difference across each appliance is equal to the supplied voltage. The total effective resistance of the circuit can be reduced by connecting electrical appliances in parallel.



Why do we use parallel circuit arrangement for domestic wiring?

A parallel circuit divides the current through the electrical appliances. The total resistance in a parallel circuit is decreased. This is helpful particularly when each gadget has different resistance and requires different current to operate properly. When one component of the circuit fails rest of them work properly.

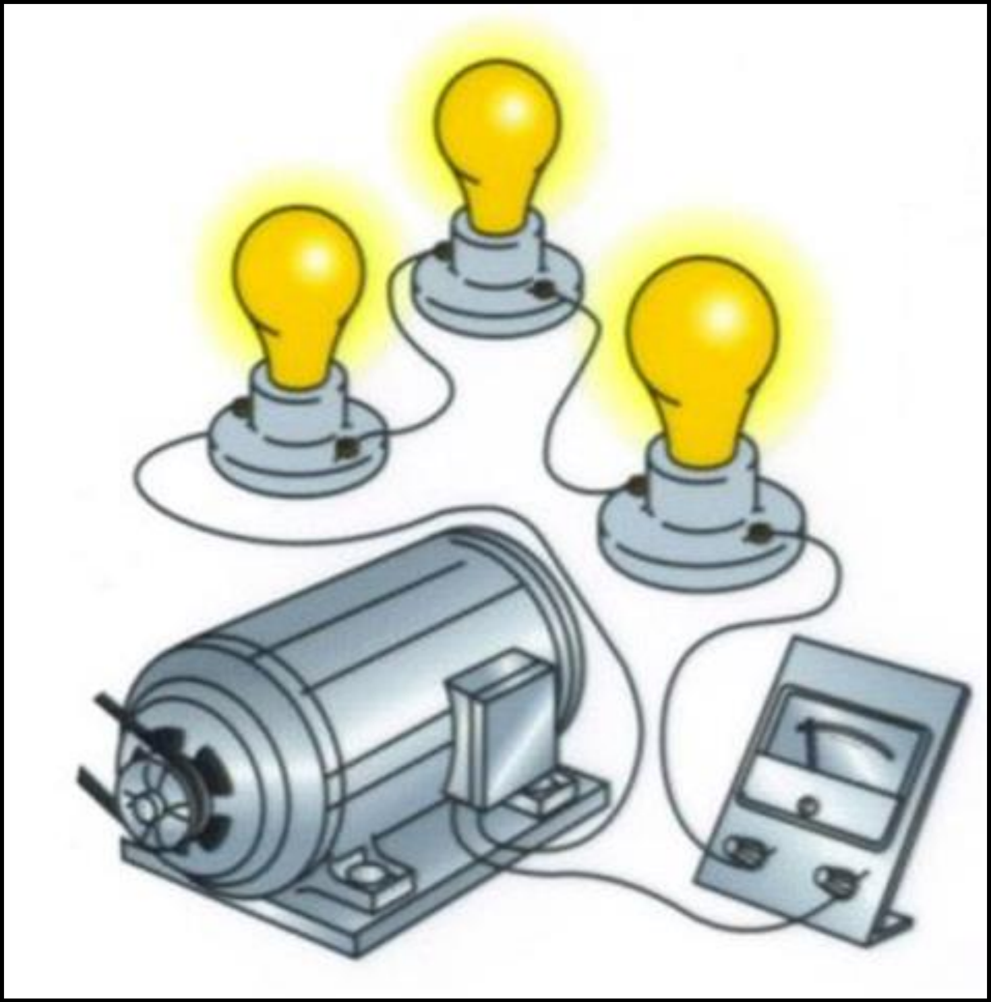
Why do we use parallel circuit arrangement for domestic wiring?



What are the disadvantages of connecting electrical devices in series?

In a series circuit the same amount of current passes throughout the electric circuit. This is impractical to connect an electric bulb and an electric heater in series; because they need currents of widely different values to operate properly. Another major disadvantage of a series circuit is that when one component fails the circuit is broken and none of the components works.

What are the disadvantages of connecting electrical devices in series?



Heating effect of electric current

The effect of electric current due to which heat is produced in a wire when current is passed through it is called heating effect of current or Joule heating.

Joule's law of heating

The amount of heat produced in a conductor is:

(i) Directly proportional to the square of the current through the conductor i.e. $H \alpha I^2$

(ii) Directly proportional to the resistance of the conductor i.e. $H \alpha R$

(iii) Directly proportional to the time for which the current is passed i.e. $H \alpha t$

Expression for work done in a conductor

$$W = Q \times V$$

But $Q = I \times t$ and $V = I \times R$

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

$$W = I^2 \times R \times t$$

Why does the cord of an electric heater not glow while the heating element does?

The heating element of an electric heater is a resistor. The amount of heat produced by it is proportional to its resistance. The resistance of the element of an electric heater is very high. As current flows through the heating element, it becomes too hot and glows red. On the other hand, the resistance of the cord is low. It does not become red when current flows through it.

Electric power

Electric power of an appliance is the rate at which it consumes electric energy.

OR

It is the rate at which work is done in maintaining an electric current in an electric circuit.

Expression for Electric power

$$\text{Electric power } P = \frac{W}{t} = \frac{VIt}{t} = VI$$

$$P = VI = IRxI = I^2R$$

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

SI unit of Electric power

SI unit of power is watt.

One watt is the power consumed by a device that carries 1A of current when operated at a potential difference of 1V.

Watt-hour

Watt-hour is defined as the electric energy consumed by an appliance of 1 watt in one hour.

Commercial unit of electrical energy

The commercial unit of electrical energy is kilowatt hour (kWh).

Kilo Watt-hour

A kilowatt-hour is the energy supplied in 1 hour to an appliance whose power is 1kW or 1000W.

1kWh = 1 kilowatt x 1 hour = 1000 watt x 3600 seconds

= 3.6×10^6 watt second.

1kWh = 3.6×10^6 J

Exercise (MCQ)

1. **A piece of wire of resistance R is cut into five equal parts. These parts are then connected in parallel. If the equivalent resistance of this combination is R', then the ratio R/R' is:**

(a) 1/25
(b) 1/5
(c) 5
(d) 25

$$\frac{1}{R'} = \frac{5}{R} + \frac{5}{R} + \frac{5}{R} + \frac{5}{R} + \frac{5}{R} = \frac{5+5+5+5+5}{R} = \frac{25}{R}$$

$$\frac{1}{R'} = \frac{25}{R} \Rightarrow \frac{R}{R'} = 25$$

Therefore, the ratio $\frac{R}{R'}$ is 25.

2. Which of the following terms does not represent electrical power in a circuit?

(a) I^2R

(b) IR^2

(c) VI

(d) V^2/R

3. An electric bulb is rated 220 V and 100 W. When it is operated on 110 V, the power consumed will be:

(a) 100 W
(b) 75 W
(c) 50 W
(d) 25 W

$$\Rightarrow R = \frac{V^2}{P}$$

where, Power rating, $P = 100$ W , Voltage, $V = 220$ V

Resistance, $R = \frac{(220)^2}{100} = 484\Omega$

$$\therefore P' = \frac{(V')^2}{R} = \frac{(110)^2}{484} = 25W$$

Therefore, the power consumed will be 25 W.

4. Two conducting wires of the same material and of equal lengths and equal diameters are first connected in series and then parallel in a circuit across the same potential difference. The ratio of heat produced in series and parallel combinations would be:

(a) 1:2

(b) 2:1

(c) 1:4

(d) 4:1

END