Chapter-13

Current Electicity

"The branch of Physics which deals with the charges in motion is called Current electricity."

13.1 Electric Current

"Rate of Flow of charge is called current."

Let ΔQ charge Flows across any crossection of wire in a time Δt. Then the current Flowing through the conductor is

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

SI-Unit of electric current is: "Ampere".

Ampere:

(i) "When one coulomb of charge passes through any crossection of a wire is one second, current is one ampere."

OR

(ii) "When the rate of flow of charge is one coulomb per second, current is one ampere."

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

$$1\ \text{ampere} = \frac{1\ \text{Coulomb}}{1\ \text{Second}} \quad \text{or} \quad A = \frac{C}{s}$$

$$A = Cs^{-1}$$

Current flows due to the flow of 'Charge Carriers'.

1- In Electrolytes charge carriers are +ve and −ve ions. e.g, in $CuSO_4$ solution charge carriers are Cu^{++} and SO_4^{--} ions.

2- In Gases charge carriers are electrons and ions.

In Semiconductors charge carriers are electrons and holes.

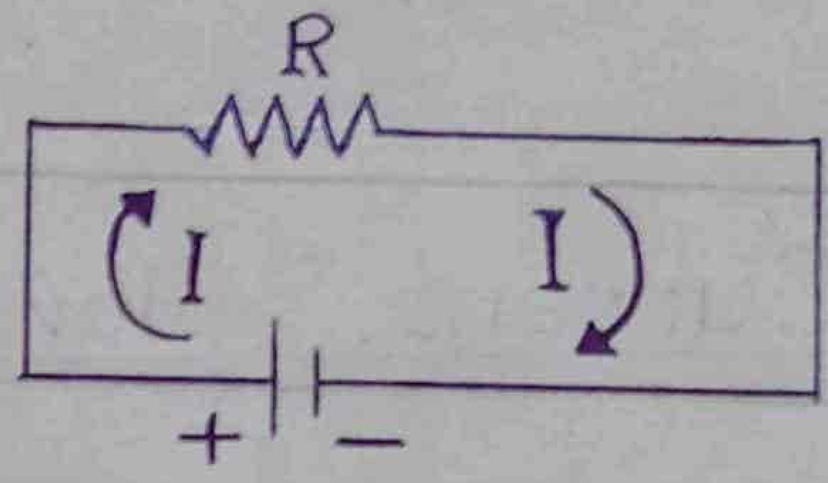
Current Direction

Conventional Current

The current due to

the Flow of equivalent amount of positive charge is called conventional current. This current Flows from a point of higher potential to a point at lower potential as if it represented a movement of positive charges."

It Flows from +ve to −ve terminal of the battery through the external circuit.



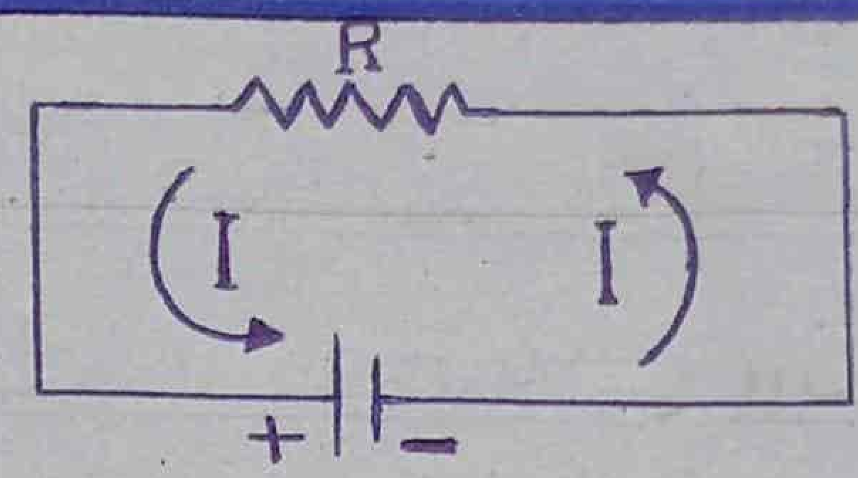
Explanation

Early scientists believed that the current is due to the Flow of +ve charges. Later on (بعد میں) it was Found that the current in metallic conductors is due to the Flow of −ve charges i.e electrons.

Note:

Now it is a convention to take the direction of current in which positive charge Flows i.e, the direction of conventional current. So, in circuit analysis we use the direction of conventional current.

Electronic Current



"The current due to the flow of negative charges (electrons) is called electronic current."

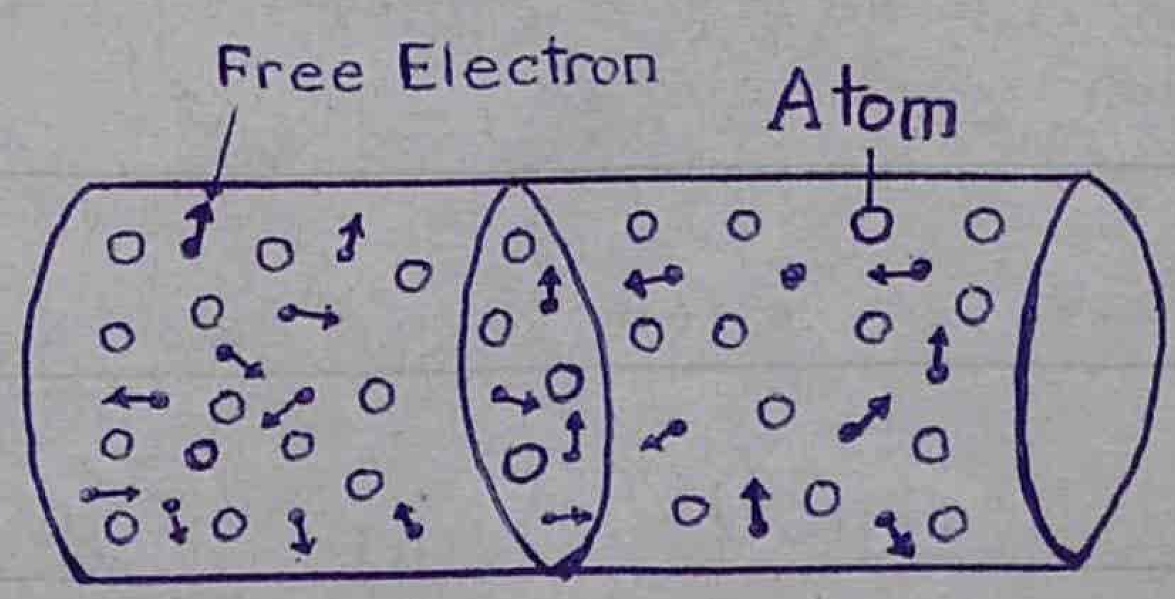
It flows from negative to positive terminal of the battery, through an external circuit.

Current through metollic conductor

In case of metallic conductors, the charge carriers are free electrons.

Free Electrons:

In a metal valance electrons are not attached to individual atoms. They are free to move about within the body of the conductor. These electrons are called Free electrons.

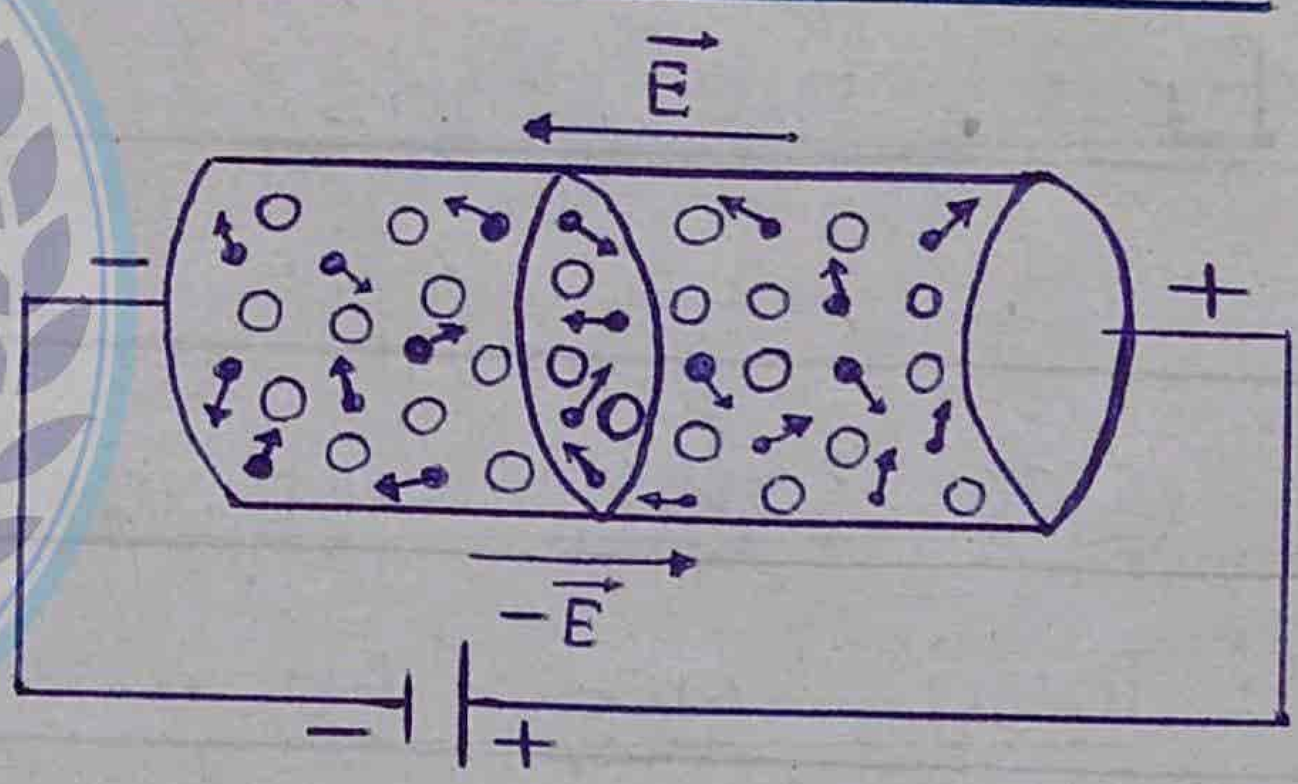


Free electrons are in random motion in a conduct as shown in Fig.

The speed of randomly moving free electrons depend upon the temperature of the conductor.

If we take any crossection of a metallic wire the number of free electrons passing through it from left to right is equal to the number of free electrons passing through it from right to left. So, the total number of free electrons passing through it is zero. Hence the net charge flow in the wire is zero.

When battery is connected across the wire



When the ends of the wire are connected with a battery, an electric field is set up at every point within the wire as shown in Fig.

Force $F = qE = -e\vec{E}$ will act on the free electrons. Hence the free electrons will move in the direction of $-\vec{E}$.

Note that the force experienced by the free electrons does not produce a net acceleration because electrons keep on colliding with the atoms of the conductor. They transfer their energy to the lattice atoms. Therefore the free electrons acquire a uniform velocity called "Drift Velocity".

Drifty Velocity:

The uniform velocity acquired by the electrons in the presence of electric field of battery is called drift velocity.

It is in the direction of $-\vec{E}$. The drift velocity is of the order of $10^{-3}\,ms^{-1}$ (Few millimeter per second).

Whereas

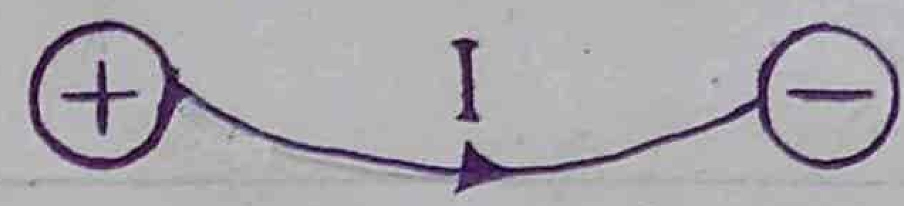
The velocity of the free electrons at room temperature due to their thermal motion is "Several hundred Kilometers per second".

Steady Current:

When a constant potential

diffence is maintained across the ends of a wire, it produces a net electric field $\vec{E}$ in the wire, so a steady current flows through the wire.

13.2 Sources of current



When two conductors at different potentials are joined by a metallic wire, current will flow through the wire. This current will continue to flow from a higher potential to the lower potential until both are at the same potential. After this the current will stop to flow. The current through the wire decreases from maximum value to zero.

Definition of Source of Current

In order to have a constant current through a conductor a source of constant potential difference should be maintained across the conductor. This is called

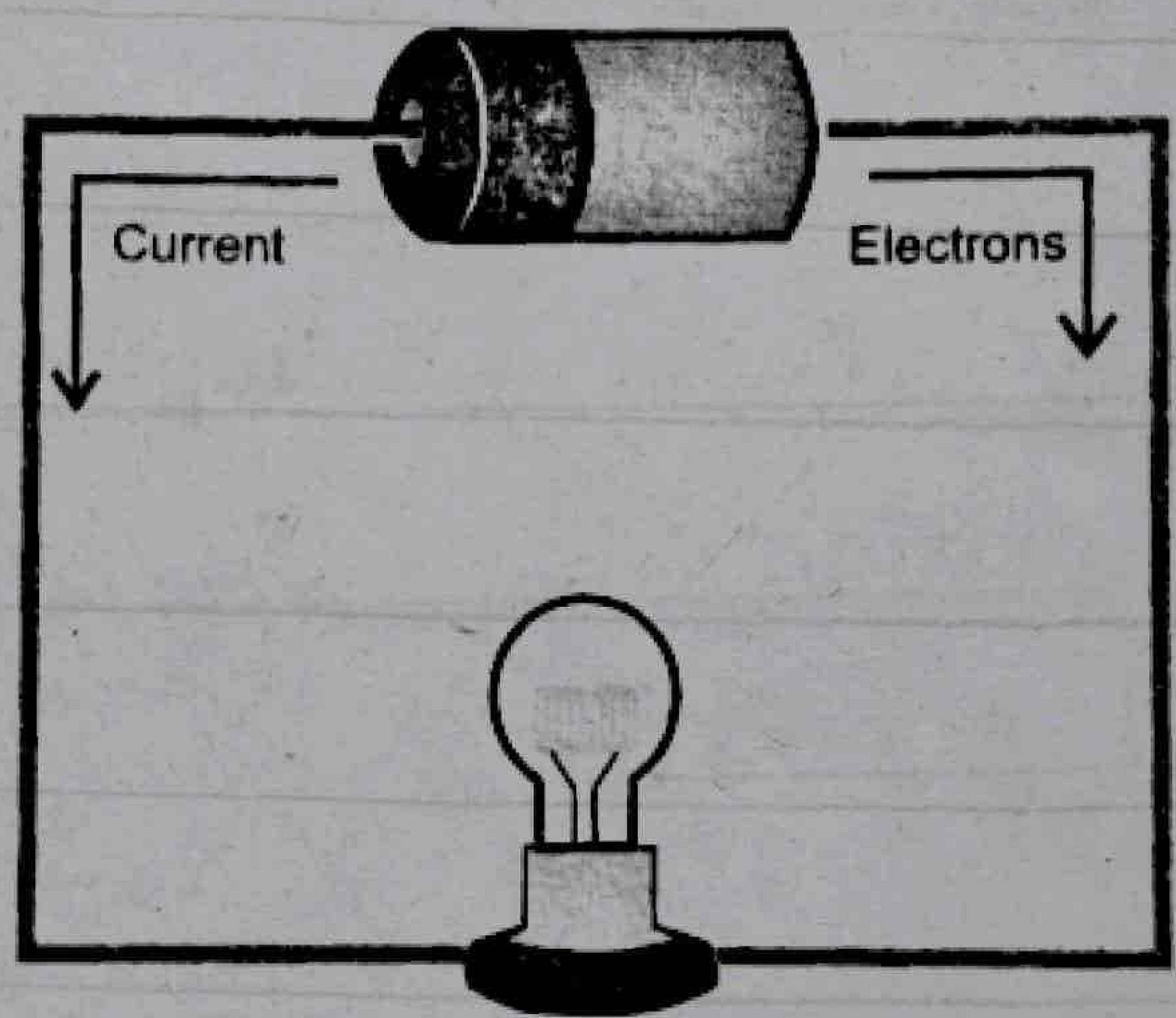


Fig. 13.4 A source of current such as battery maintains a nearly constant potential difference between ends of a conductor.

Source of current.

Every source of current converts some non-electrical energy such as chemical energy, mechanical energy, heat energy or solar energy into electrical energy.

Examples of Sources of Current:

1- Cells:

They convert chemical energy into electrical energy.

2- Electric Generators:

They convert mechanical energy into electrical energy

3- Thermocouples:

They convert heat energy into electrical energy.

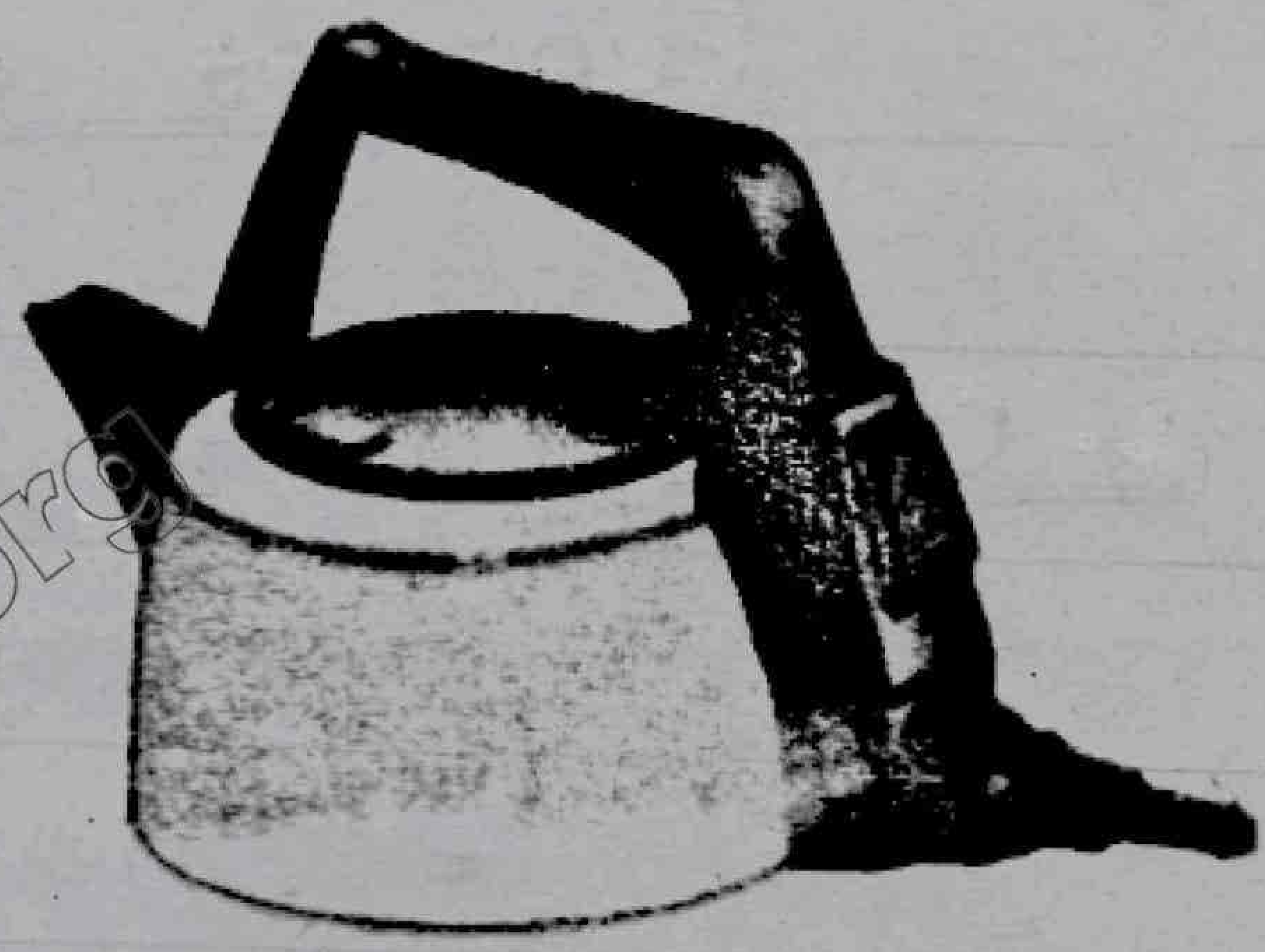
4- Solar Cells:

They convert sunlight directly into electrical energy.

13.3 Effects of Current

1) Heating Effect
2) Magnetic Effect
3) Chemical Effect

1) Heating Effect



Heating effect of current is used in electric kettle.

Current flows through a wire due to motion of free electrons. During the motion, they collide with the atoms of the metal. At each collision they lose some of their Kinetic energy and give it to the atoms. In this way flow of electrons increases the kinetic energy of the atoms. It produces heat in the wire. The heat "H" produced by the current I in the wire of resistance "R" during a time interval "t" is

$$H = I^2Rt$$

This is also called Joule's Law.

Applications:

Heating effect of current is used in

(i) Electric Heaters (ii) Electric kettles

(iii) Toasters (iv) Electric iron etc.

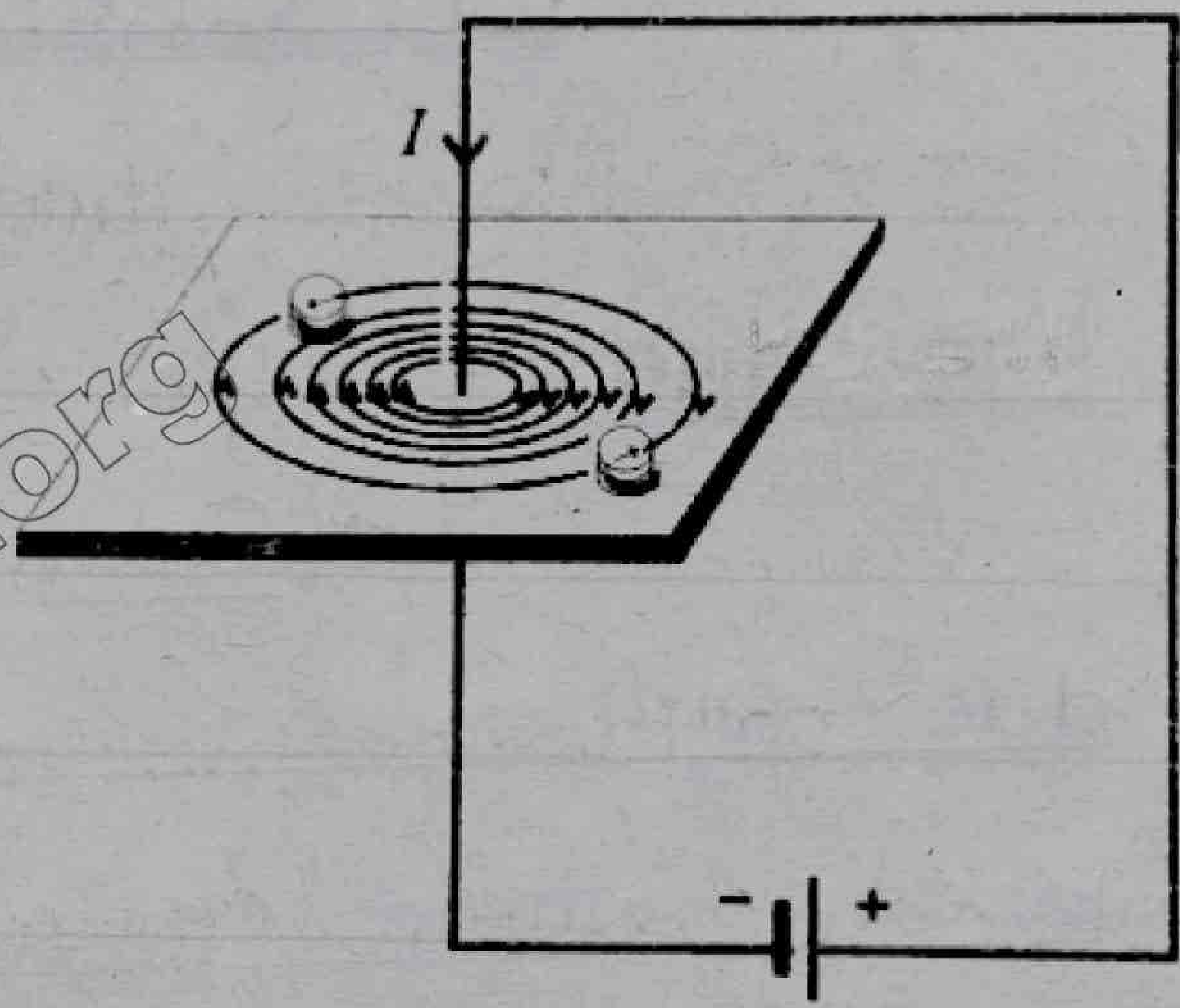
2) Magnetic Effect

When current I Flows through a wire magnetic Field is produced around it. The magnetic Field strength B depends upon:

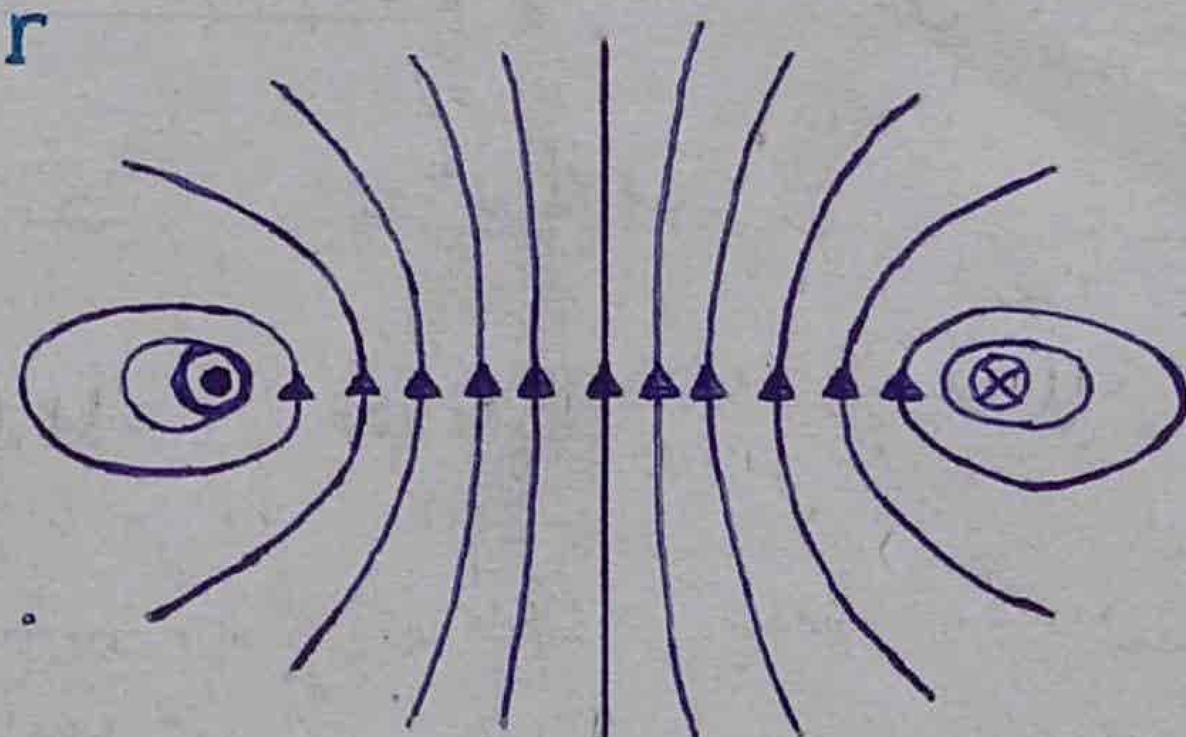
(i) The value of current $B \propto I$

(ii) The distance From the wire $B \propto \frac{1}{r}$

The pattern of the magnetic Field produced by Fig(a). A current carring straight wire. Fig (b) a current carring single circular turn.

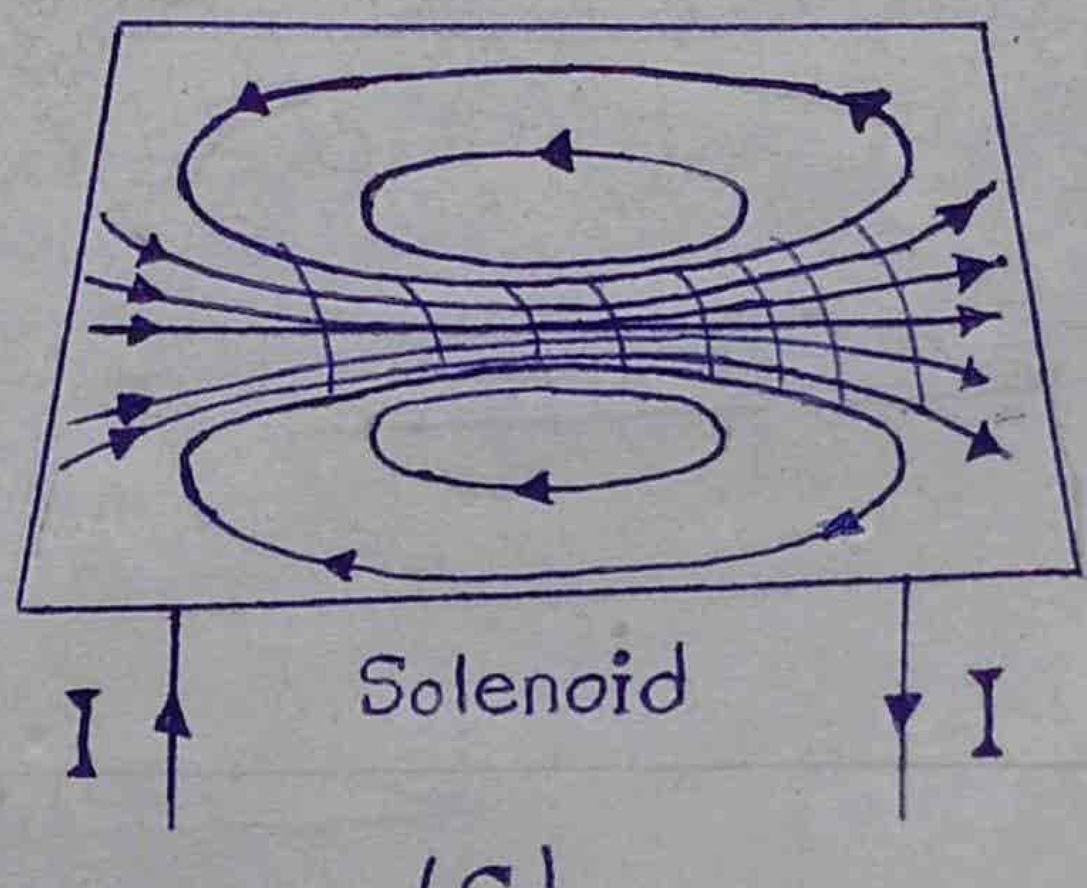


(a)



(b)

(C) a current carring solenoid is Shown in Fig (a), (b) and (c) respectively.



(c)

Applications:

1)- Magnetic effect is used in detection and measurement of current.

2)- All the machines involving electric motors also use the magnetic effect of current.

3) Chemical Effect

Electrolysis:

Certain liquids conduct electricity due to some chemical reactions that take place within them. The study of this process is known as electrolysis.

e.g

Dilute Sulphuric Acid Solution H_2SO_4 and copper sulphate solution $CuSO_4$.

The chemical changes produced in electrolysis depend upon the nature of the liquid and the quantity of current passing through the liquid.

Electrolyte:

A liquid which conducts electric is current electrolyte.

1- Electrode:

The material in the Form of wire or rod or plate which leads the current into or out of the electrolyte is called electrode.

2- Anode:

The electrode connected with the positive terminal of the battery is called anode.

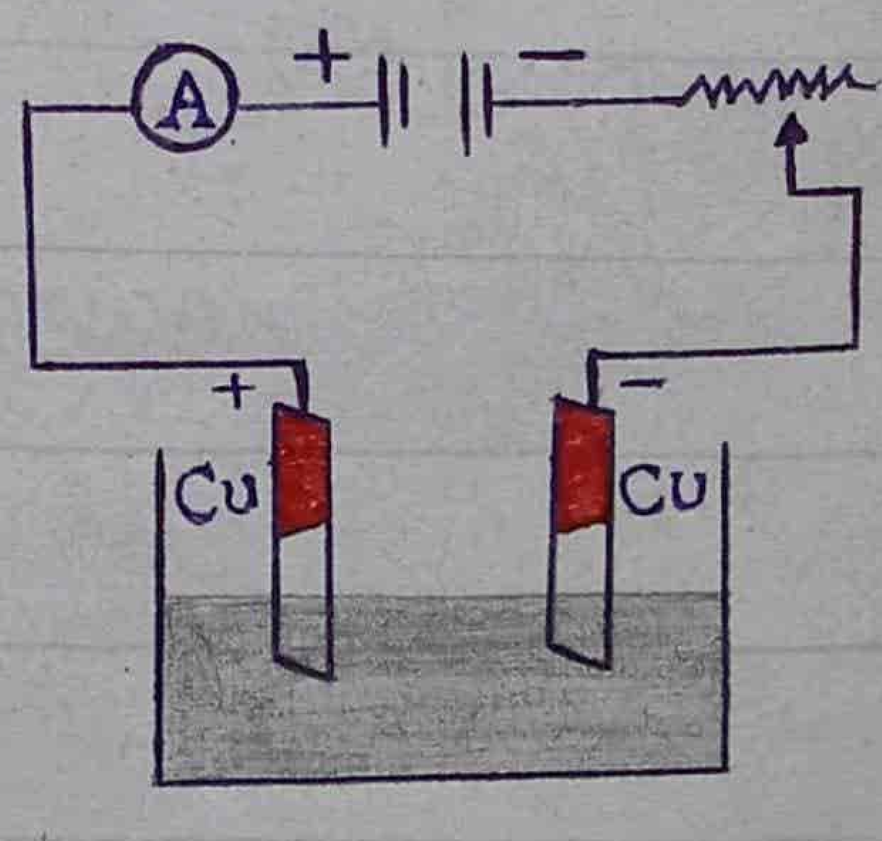
3- Cathode:

The eletrode connected with the negative terminal of the current source (battery) is called cathode.

4- Voltameter:

The vessel containing the two electrodes and an electrolyte is called a voltameter.

Explanation:



Consider electrolysis of copper sulphate $CuSO_4$. The voltameter contains dilute solution of $CuSO_4$. Anode and Cathode are both copper plates as shown in Fig.

When $CuSO_4$ is dissolved in water, it dissociates in Cu^{++} and SO_4^{--} ions. When current passes through the voltameter, Cu^{++} ions move towords the Cathode and the Following reaction take place.

$$Cu^{++} + 2e \longrightarrow Cu$$

These Cu atoms are deposited on the cathode plate. While Cu^{++} is deposited on the cathode, the SO_4^{--} ions move towards the anode.

Cu atoms from the anode go into the solution as copper ions which combine with sulphate ions to Form $CuSO_4$.

$$Cu^{++} + SO_4^{--} \longrightarrow CuSO_4$$

During electrolysis copper is continuously deposited on the cathode while an equal amount of copper is dissolved in the solution from anode. So, the density of copper sulphate solution remains unchanged.

Electroplating:

The process of coating (تہہ چڑھانا) a thin layer of some expensive metal (gold, silver) on an article of some cheap metal is called electroplating.

13.4 OHM'S LAW

Statement:

Current flowing through a conductor is directly proportional to the potential difference across its ends provided the physical state of the conductor remains constant.

$$V \propto I$$

$$V = \text{constant} \times I$$

$$V = R \times I$$

$$\boxed{V = IR}$$

The constant of proportionality R is called Resistance of conductor.

The value of R depends upon the

(i) nature (ii) dimensions

(iii) Physical state of the conductor.

Resistance

The opposition offered to the flow of charge carriers by the conductor is called resistance.

Reason:

The opposition to the motion of electrons is due to their continuous collision with the atoms of the lattice.

Unit of resistance is OHM.

OHM

A conductor has a resistance of one ohm if a current of one ampere flows through it when a potential difference of one volt is applied across its ends.

The symbol of ohm is "Ω" (omega).

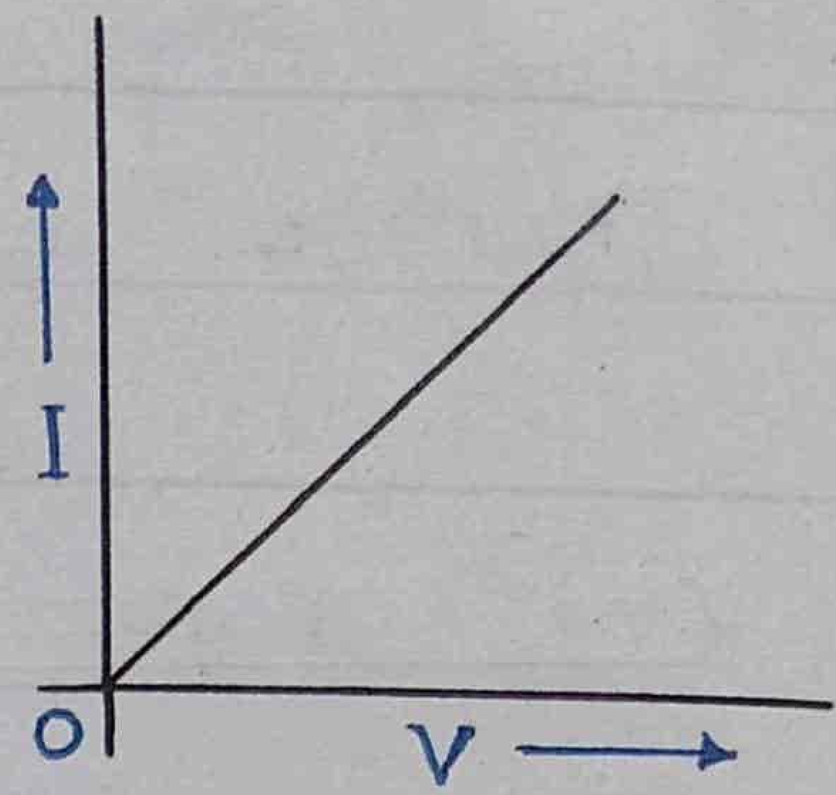
$$R = \frac{V}{I}$$

$$1\ \text{ohm} = \frac{1\ \text{volt}}{1\ \text{ampere}} = \frac{V}{A}$$

$$\text{ohm} = VA^{-1}$$

$$R(\text{ohm}) = \frac{V(\text{volts})}{I(\text{ampere})}$$

Ohmic and Non-ohmic conductors:



Fig(1)

A conductor is said to obey Ohm's Law, if its resistance "R" remains constant and the graph between "V" and "I" is a straight line. Fig (1)

Ohmic:

A conductor which strictly obeys ohm's law is called ohmic.

Non-Ohmic:

A conductor which does not obey ohm's law is called non-ohmic. e.g

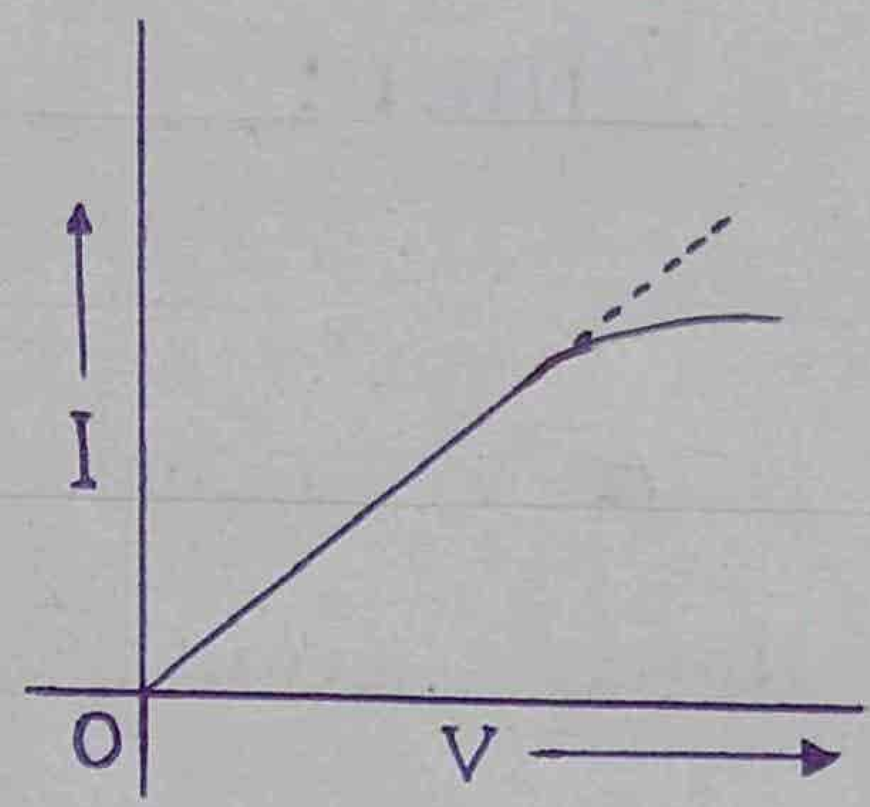
(i) Filament of a bulb

(ii) A semiconductor diode

1- Filament of a bulb

Apply a certain potential difference across the terminals of a Filament lamp. Measure the current passing through it. If we repeat the measurements for different value of potential difference and draw a graph between "V" and "I".

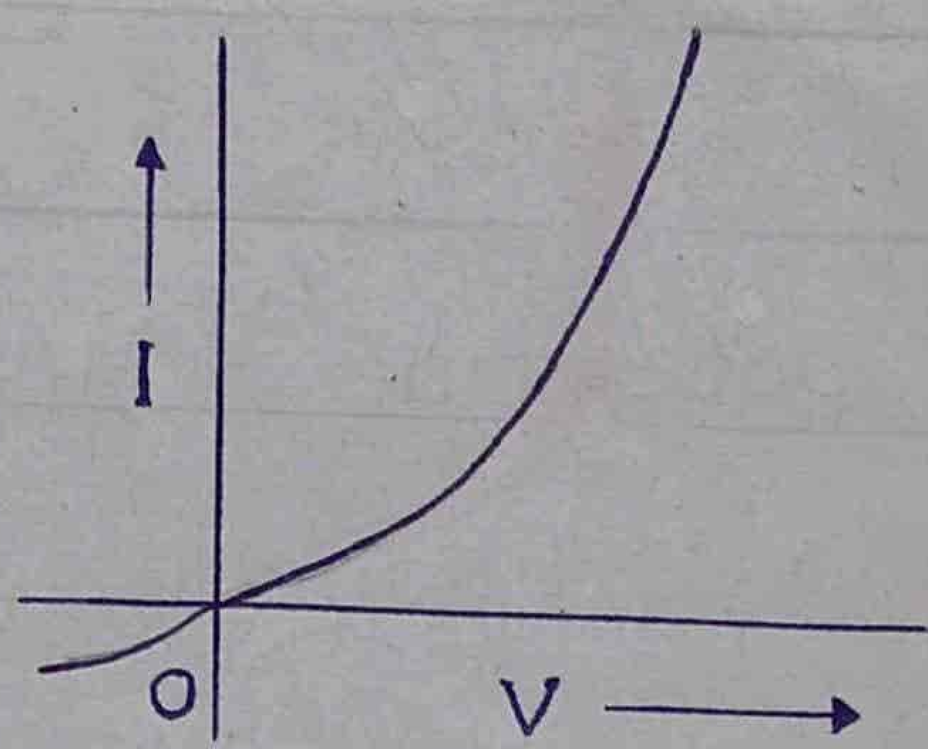
The graph is not a straight line Fig (2). It means that Filament is a non-ohmic device. The deviation of V-I graph from the straight line is due to the increase in the resistance of the filament with temperature.



Fig(2)

When the current passing through the filament is increased from zero, the graph is a straight line in the intial stage. As the current is small, the increase in temperature is very small. Hence the change in resistance is negligible. When the current is further increased, the resistance of the filament continues to increase due to rise of temperature.

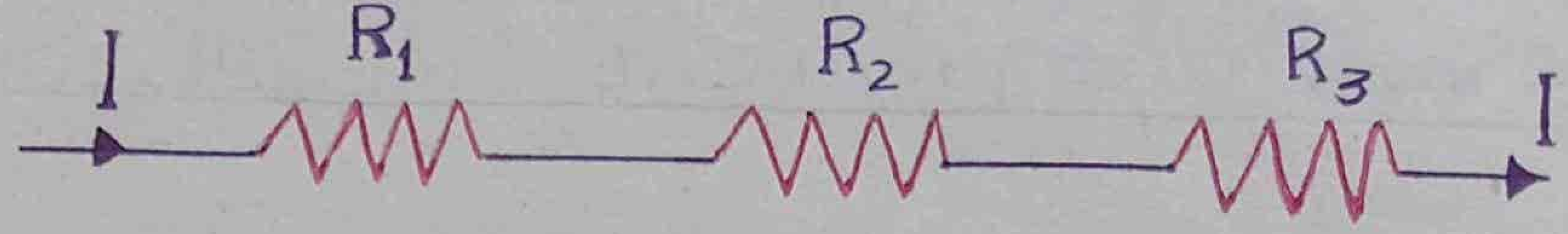
2- Semiconductor Diode:



Semiconductor diode is a non-ohmic device. V-I graph is shown in Fig. Figure shows that graph is not a straight line, so, a semiconductor diode is a non-ohmic device.

Combination of Resistors

1- Series Combination:



$$R_e = R_1 + R_2 + R_3$$

When the resistors are connected end to end such that the same amount of current passes through all of them, they are said to be connected in series.

The equivalent resistance R_e is

$$R_e = R_1 + R_2 + R_3 + \ldots\ldots$$

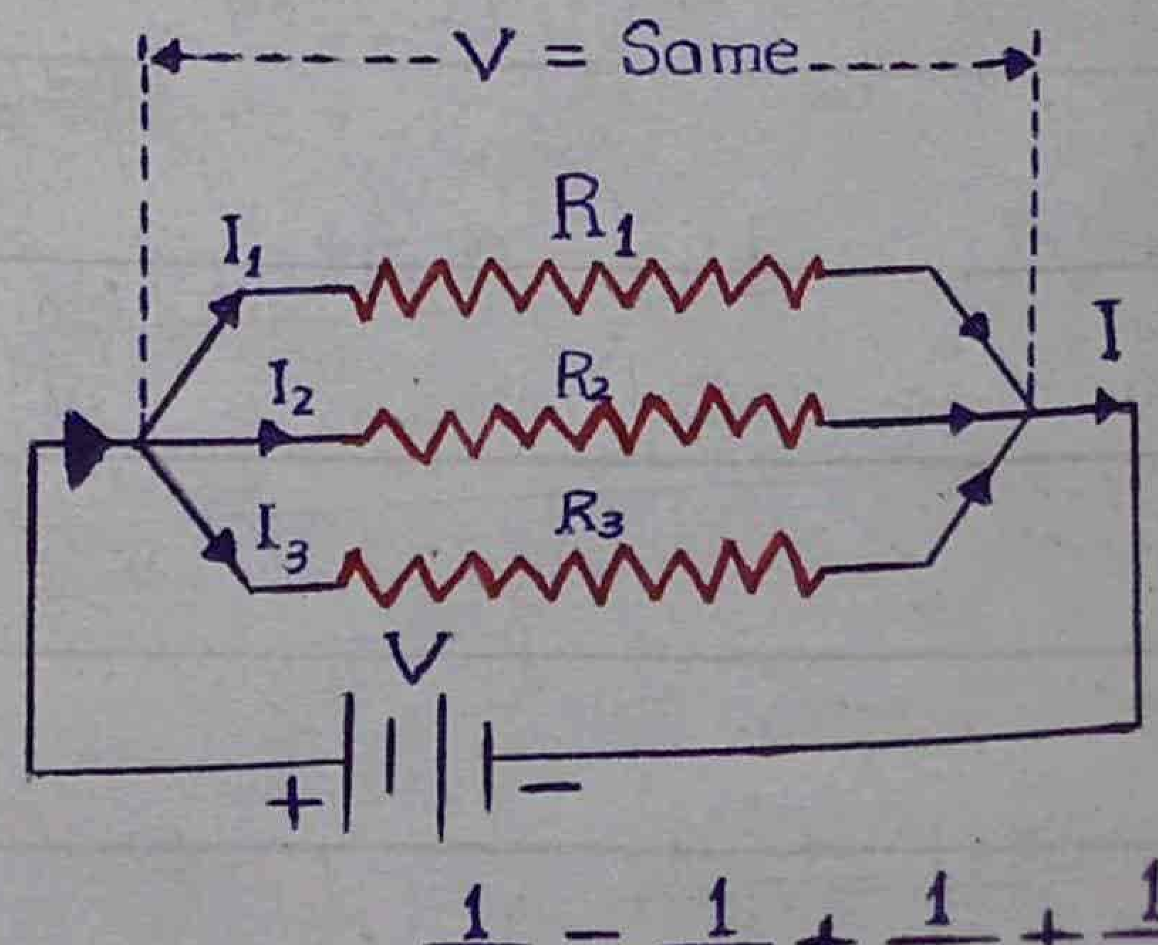
(i) The equivalent resistance increases.

(ii) R_e is greater than the greatest resistance in series.

(iii) Current I = Same in all resistors.

(iv) Potential difference V = IR divides acording to the values of resistances R_1, R_2, R_3 etc.

2- Parallel Combination



When the resistors are connected side-by-side

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

with their ends joined together, they are said to be connected in parallel.

Their equivalent resistance R_e is

$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots\cdots$$

(i) Potential difference V = same across all the resistors.

(ii) Current $I = \frac{V}{R}$ divides according to the values of resistances.

(iii) The equivalent resistance decreases.

(iv) The equilant resistance is smaller then the smallest resistance connected in parallel.

13.5 Resistivity and is dependance upon temperature

Resistivity:

"Resistance of one meter cube of a material is called resistivity or specific resistance."

Symbol: ρ (rho)

Formula:

At constant temperature, resistance of a conductor depends upon following factors:

1- Resistance is directly proportional to its length

2- Resistance is inversely proportional to its area of crossection.

3- R depends on the nature of its material.

$$R \propto L$$

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

Combining

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

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

Unit:

$$\rho = \frac{RA}{L} = \frac{\text{ohm} \times m^2}{m} = \text{ohm} \times m \quad (\Omega m)$$

Unit of resistivity is ohm-meter.

Difference between Resistance and Resistivity

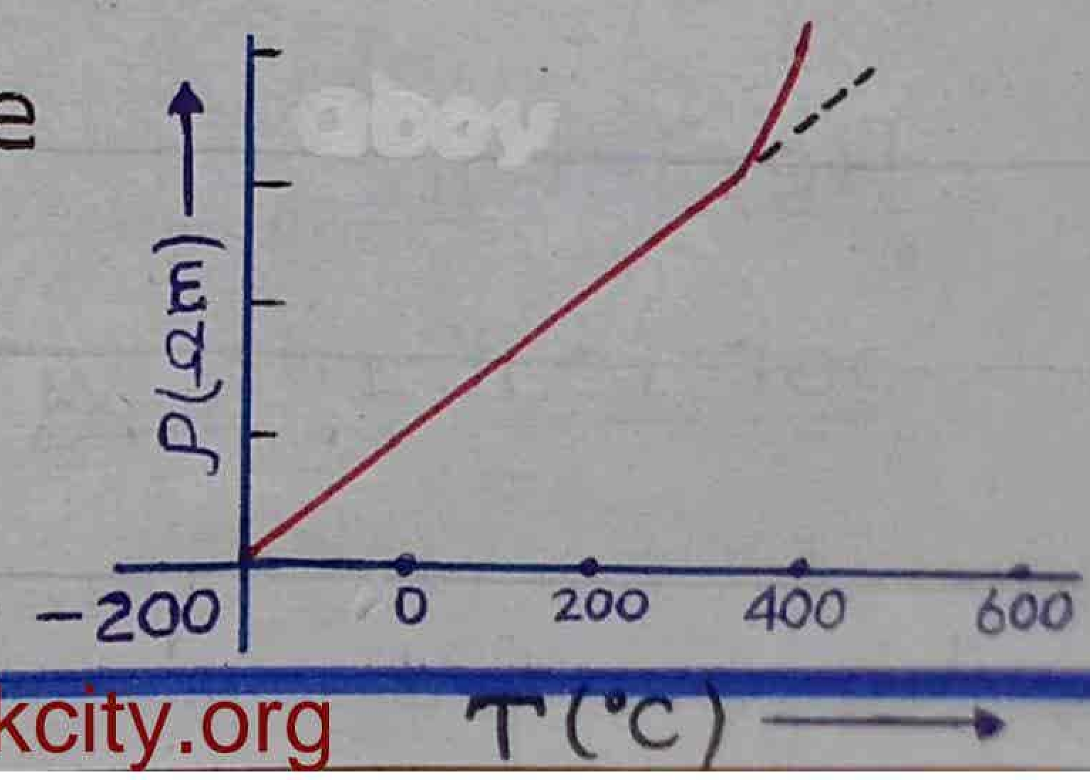
Resistance is the characteristic of a particular wire, whereas the resistivity is the property of the material of which the wire is made.

Dependance of resistivity on temperalure:

Resistivity ρ of a material depends upon its temperature.

The resistance of a material is due to collision of free electrons with the atoms of the lattice. As the temperature of a conductor rises, the amplitude of vibration of the atoms increases. So the changes of collision of free electrons with vibrating atoms also increases. We can say that the atoms offer bigger target. Hence, the resistance of the conductor increases.

Experimentaly it is found that the change of resistance of a metallic wire (conduclor) is nearly linear (straight line graph) over a wide range of temperature above and below 0°C.



Proof:

$$\frac{R_t - R_o}{R_o t}$$

Let R_o = Resistance of the conductor at 0°C

R_t = Resistance of the conductor at t°C

$R_t - R_o$ = Change in resistance

t = rise in temperature

Experimentaly

$$R_t - R_o \propto R_o$$

$$R_t - R_o \propto t$$

Combining

$$R_t - R_o \propto R_o t$$

$$R_t - R_o = \alpha R_o t$$

$$\alpha = \frac{R_t - R_o}{R_o t}$$

$$\alpha = \frac{R_t - R_o}{R_o \Delta T}$$

α = Temperature Coefficient of Resistivity

Definition of α:

"Fractional change in resistance per kelvin is called temperature coefficient of resistance α."

Unit of temperature coeficient of resistance is K^{-1}:

$$\alpha = \frac{R_t - R_o}{R_o t} = \frac{\cancel{ohm}}{\cancel{ohm} \times K} = \frac{1}{K} = K^{-1}$$

As resistivity depends upon temperature and resistivity is directly proportional to resistance, we can express the equation (1) in terms resistivity

$$\boxed{\alpha = \frac{\rho_t - \rho_o}{\rho_o t}}$$

Here ρ_t is the resistivity at $t°C$.
ρ_o is the resistivity at $0°C$.

Unit:

$$\alpha = \frac{\cancel{ohm} \times \cancel{m}}{\cancel{ohm} \times \cancel{m} \times K} = K^{-1}$$

1-Positive Temperature Cofficient

When the resistance of a material inceases with the rise of temperature α is positive.

Table 13.1

Substance	$\rho(\Omega m)$	$\alpha(K^{-1})$
Silver	1.52×10^{-8}	0.00380
Copper	1.54×10^{-8}	0.00390
Gold	2.27×10^{-8}	0.00340
Aluminum	2.63×10^{-8}	0.00390
Tungsten	5.00×10^{-8}	0.00460
Iron	11.00×10^{-8}	0.00520
Platinum	11.00×10^{-8}	0.00520
Constanton	49.00×10^{-8}	0.00001
Mercury	94.00×10^{-8}	0.00091
Nichrome	100.0×0^{-8}	0.00020
Carbon	3.5×10^{-5}	-0.0005
Germanium	0.5	-0.05
Silicon	20-2300	-0.07

2- Negative Temperature Coefficient:

There are some substance like Germanium, Silicon etc, whose resistance decreases with increase in temperature. They have negative temperature coefficient.

α is negative.

Conductance:

"Reciprocal of resistance is called conductance."

$$\text{Conductance} = \frac{1}{\text{Resistance}}$$

Unit of Conductance:

$\frac{1}{\text{ohm}}$ or ohm^{-1} or mho or seimen.

Conductivity:

"Reciprocal of resistivity is called conductivity."

$$\sigma = \frac{1}{\rho}$$

$$\text{Conductivity} = \frac{1}{\text{Resistivity}}$$

Unit: SI-unit of Conductivity is

$$\frac{1}{\text{ohm} \times \text{m}} = \text{ohm}^{-1}\ \text{m}^{-1} = \text{mho}\ \text{m}^{-1}.$$

13.6 Colour code for carbon resistances

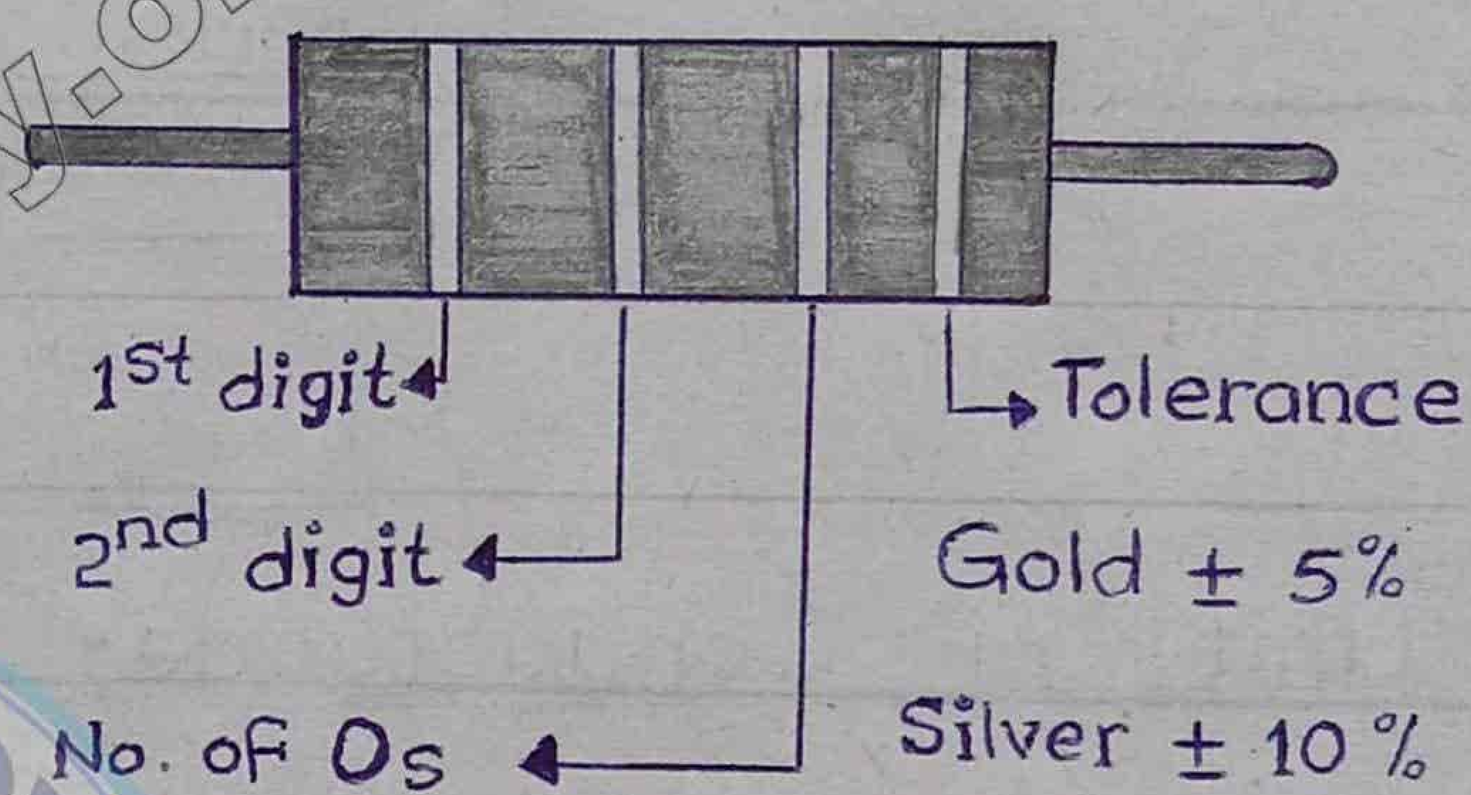
Table 13.2 The Colour Code	
Colour	Value
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Gray	8
White	9

Carbon resistances are most common in electric equipments. They consist of high grade ceramic rod or cone (called substrate) on which a thin resistive film of carbon is deposited.

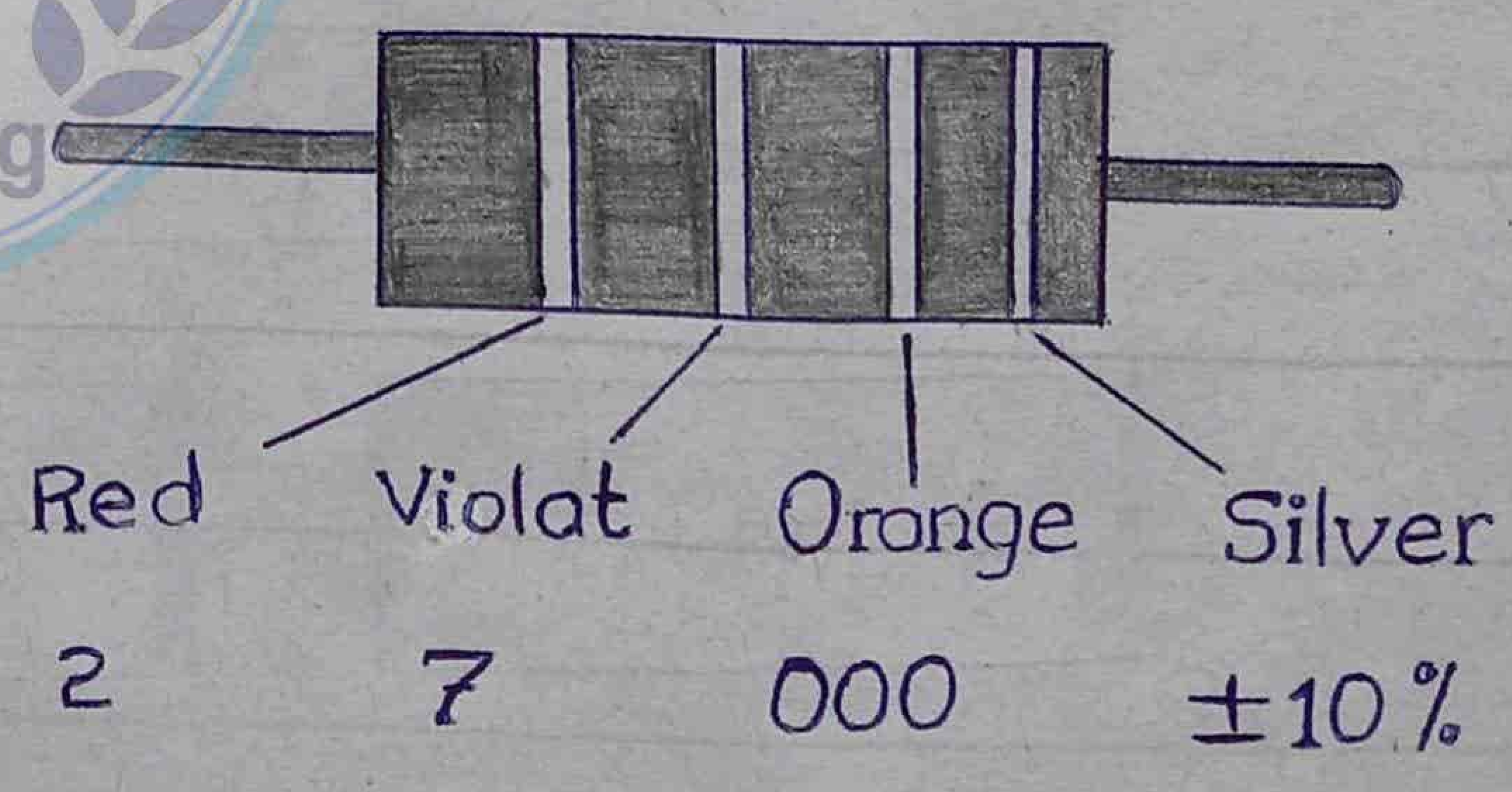
The numerical value of the resistance is indicated by a colour code. It consists of a band of different colours printed on the body of the resistor. It is given in the table.

<u>Usually code consists of 4 - Balls.</u>

Starting from Left to Right. The colour bands are explained as follow.



Resistor Colour Code



$R = 27000\,\Omega\ (\pm 10\%)$

First band:

It indicates the first digit in the numerical value of the resistance.

e.g: Red = 2

Second band:

It gives the second digit

e.g: Violet = 7.

Third band:

It is decimal multiplier.

i.e: It gives the number of zeros after the first two digits.

e.g: Orange = 000

Fourth band:

It gives resistance tolerance.

It is either 'Silver' or 'Gold'.

Silver = ± 10% ; Gold = ± 5%

If no fourth band:

Tolerance is understood to be ± 20%.

The value of resistance

R = 27000 ± 10%

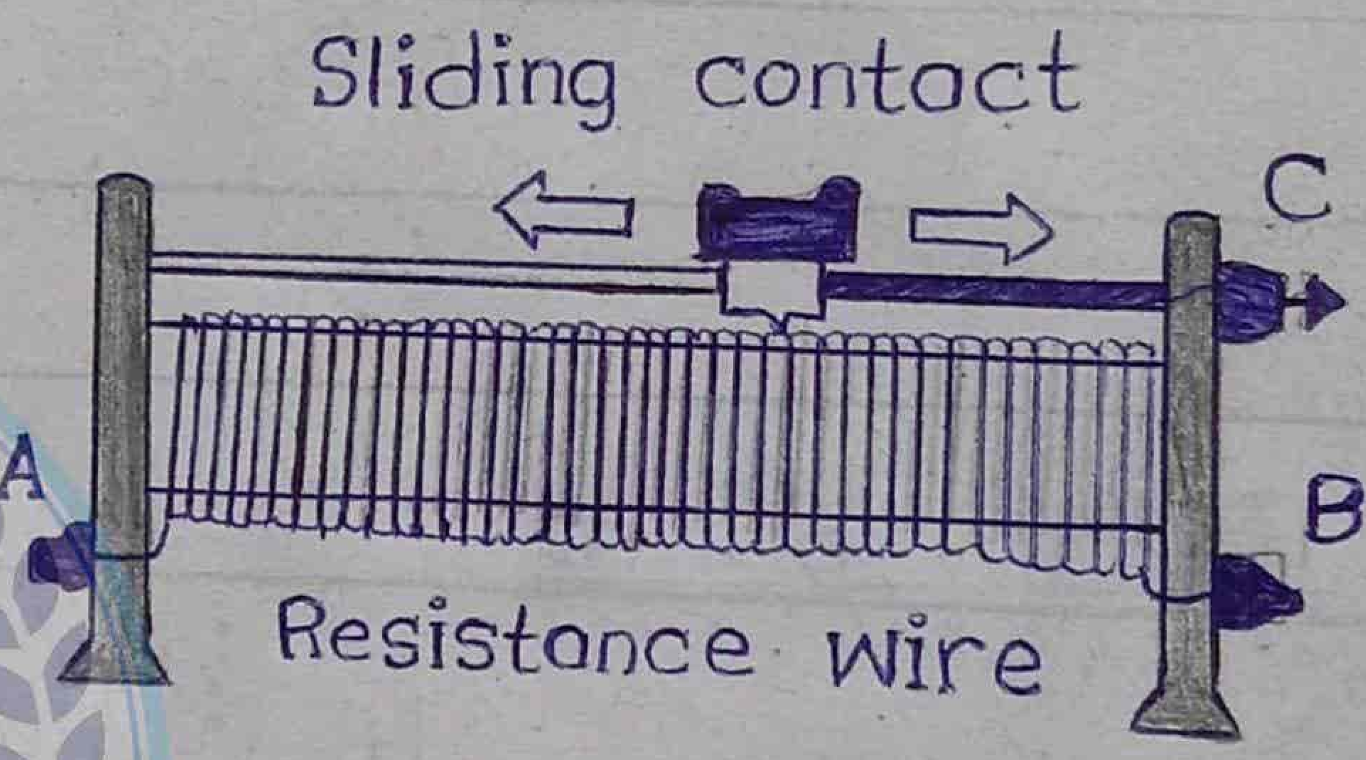
Tolerance:

Tolerance means the possible variation from the marked value.
For example a 1000 Ω resistor with a tolerance of ±10% will have an actual resistance anywhere between 900 Ω and 1100 Ω.

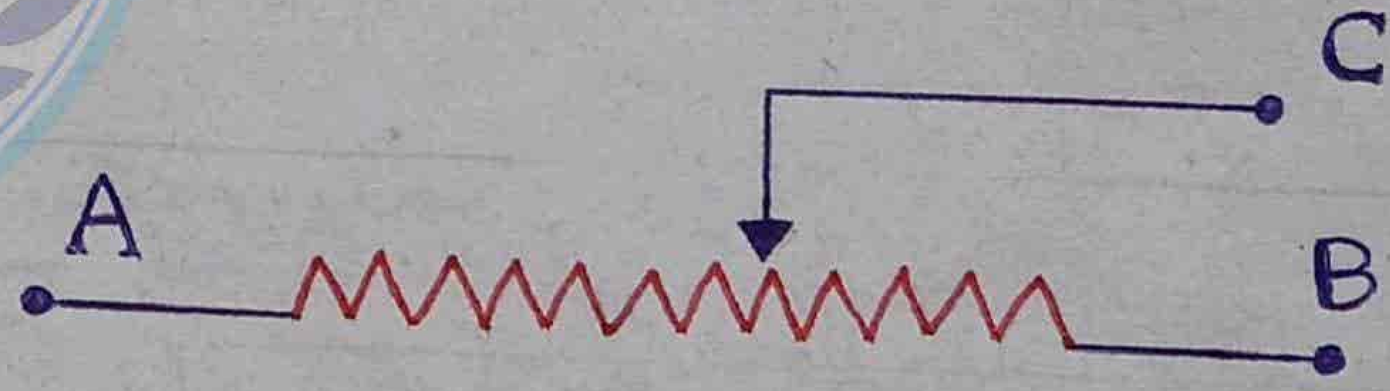
RHEOSTAT

"It is a wire wound variable resistance."

Construction:



(Fig i) A Rheostat



Its use as variable resistor
Fig (ii)

It consists of a high resistance wire, wound over an insulating cylinder. The ends of the wire are connected to the two fixed terminals "A" and "B". A third terminal C is attached to a sliding contact which can be moved over the wire.

Uses:

Rheostat can be used as

(i) Variable Resistor

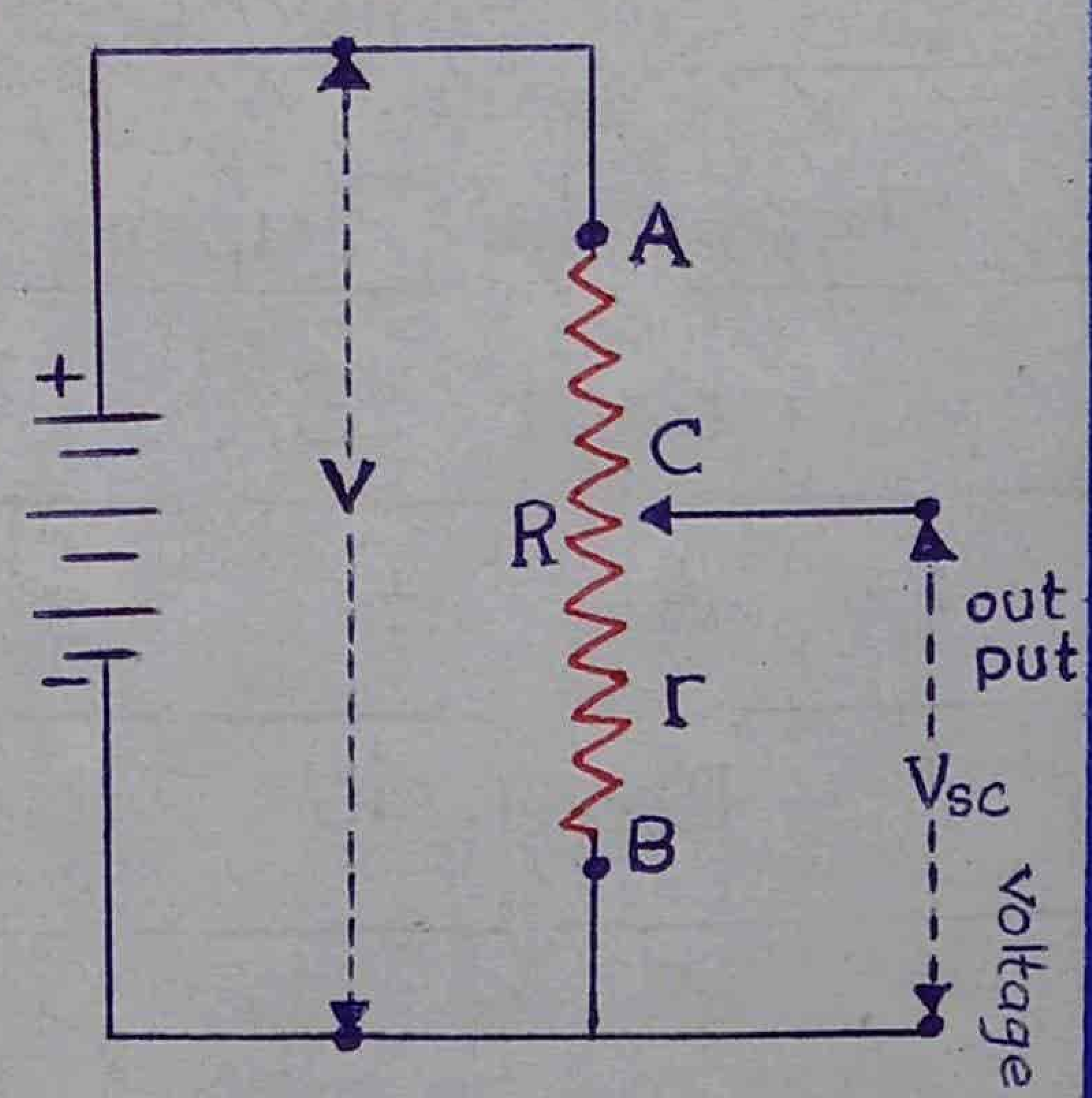
(ii) Potential Divider

Variable Resistor:

A rheostat acts as a variable resistor when terminal "A" and the sliding terminal "C" are conneted in a circuit. Fig (ii) in this way the resistance of wire between "A" and "C" is used. If "C" is moved away from "A", the resistance in the circuit increases and if "C" is moved towards "A", the resistance between "A" and "C" decreases.

Potential Divider:

The circuit shown in the Figure is called potential divider.



Use of rheostat as potential divider

Battery supplies a potential difference "V" across the ends "A" and "B" of the rheostat.

R = Resistance of the wire AB. Current through it is

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

V_{BC} = Potential difference between the portion BC of the wire

$$V_{BC} = Ir = \frac{V}{R} r = \frac{r}{R} V$$

$$\boxed{V_{BC} = \frac{r}{R} V}$$

Here r = resistance of portion BC of the wire. This circuit gives at its output terminals (B and C) a verying potential difference V_{BC} from zero to V.

$$V_{BC} = \frac{r}{R} V$$

depends upon the position of the sliding contact "C".

1. As the sliding contact "C" is moved towards the end "B", V_{BC} decreases.
2. If "C" is moved towards the end A, the output voltage V_{BC} increases.

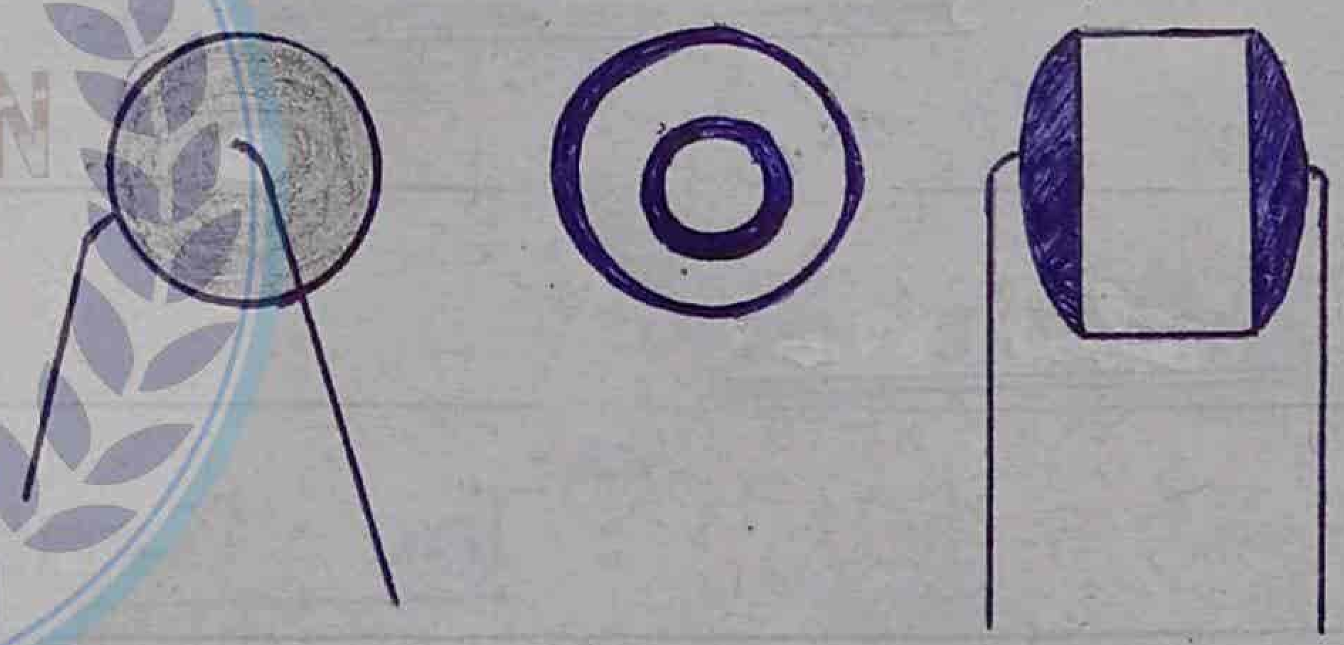
Thermistors

"A thermistor is a heat sensitive resistor."

Most of the thermistors have negative temperature coefficient of resistance. i.e the resistance of such thermistors decrease when their temperature is increased. Thermistors with positive temperature coefficient are also available.

Fabrication

Usually thermistors are made of ceramic. Semiconductor ceramic are made from mixture of metallic axides of manganese, nickle, cobalt, copper, iron etc.



Thermistors of different shapes

They are pressed into desired shapes and then baked at high temperature. Different types of thermistors are shown in Fig. They may be in the form of beads (ڈور) rods or washers.

Note:

Thermistors with high temperature coefficient of resistance are very accurate for measuring low temperature especially near 10K.

Applications:

Thermistors are used as Temperature Sensors.

They convert changes of temperature into electrical voltage or electrical signals.

13.8 Electrical Power and Power Dissipation in resistors

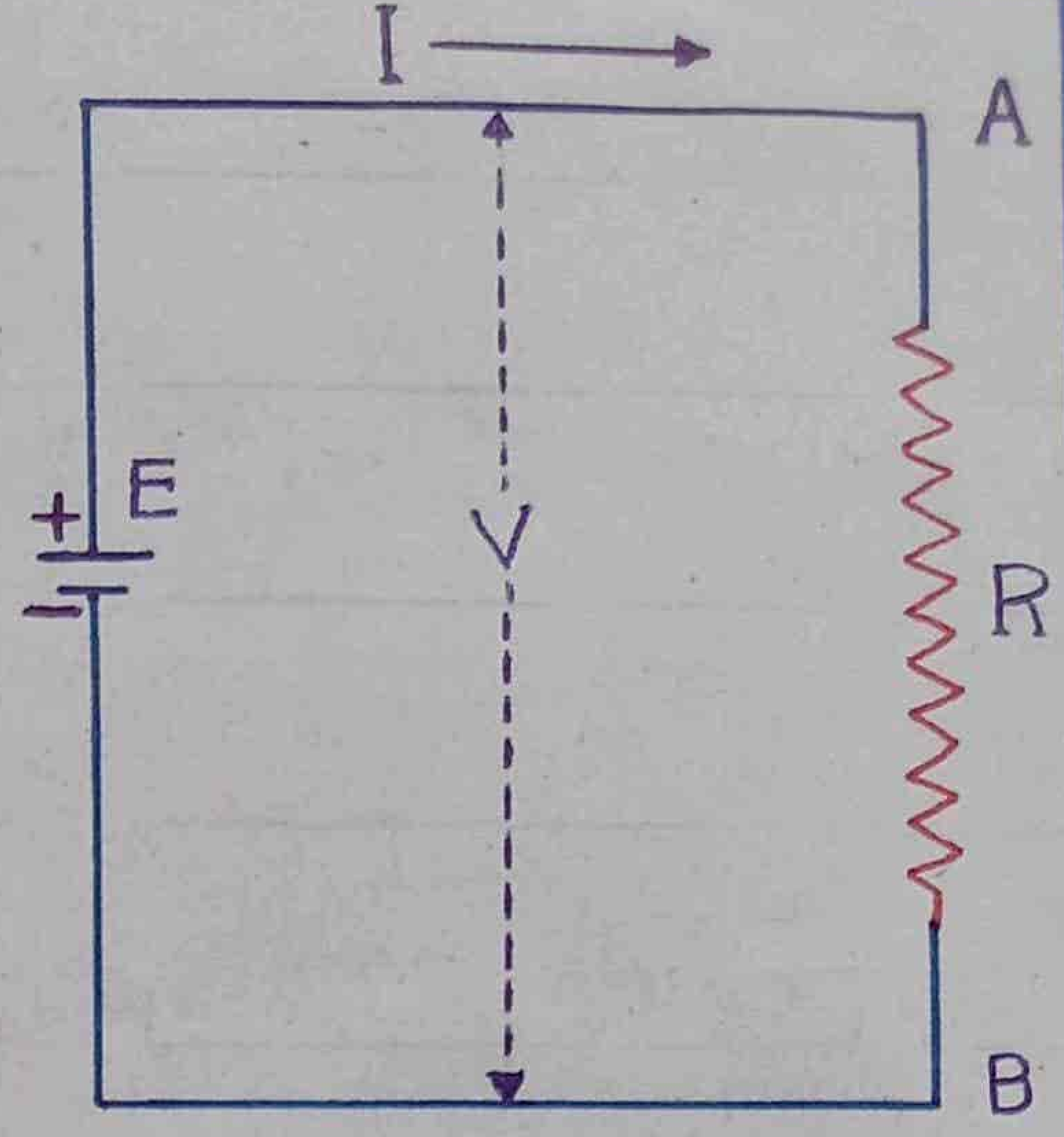
Definition:

"The rate of supply of electrical energy by the battery is called electrical power of the battery."

Explanation:

Consider a battery E is

connected in series with a resistance R.



V = Steady potential difference between the terminals A, B of the resistor R.

I = Steady current flowing through R.

Battery is continuously supplying energy or doing work ΔW in lifting charges ΔQ up through the potential difference V.

By definition

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

$$\text{Work done} = \Delta W = V \times \Delta Q$$

$$\text{Electrical Power} = \frac{\text{Energy Supplied}}{\text{Time taken}}$$

$$= \frac{\Delta W}{\Delta t}$$

$$= \frac{V \times \Delta Q}{\Delta t} = V \times \frac{\Delta Q}{\Delta t} = V \times I$$

Electrical Power = VI ——— (1)

By the law of conservation of Energy

power supplied by battery = power dissipated in the resistor R.

power dissipated = P = VI

1) As

$V = IR$ ohm's law

$P = VI$

$P = (IR)I$

$$P = I^2R$$

2) As

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

$P = VI$

$P = V\left(\frac{V}{R}\right)$

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

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

Unit of Power is **Watt**.

When

V is expressed in volts.

"I" is expressed in amperes.
"P" is expressed in watts.

$$P = V \times I$$

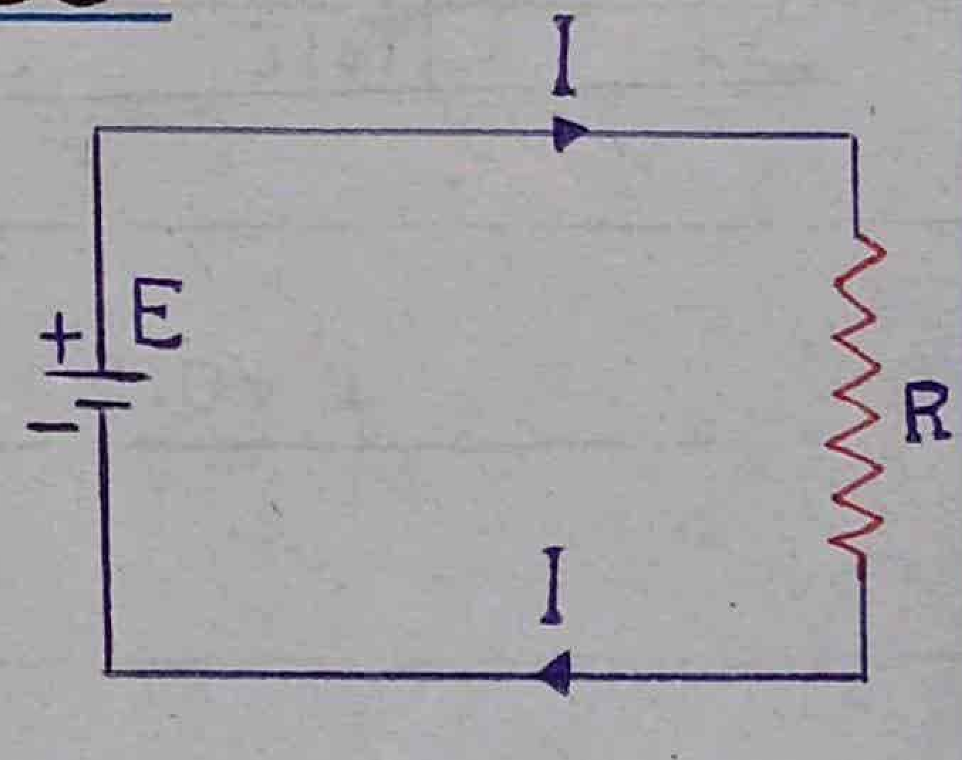
$$\text{watt} = \text{Volt} \times \text{ampere}$$

Electromotive Force (EMF) and Potential difference:

Electromotive Force:

"The amount of energy supplied to a unit charge by the cell is called emf E of the source."

$$E = \frac{\Delta W}{\Delta Q}$$



Explanation:

When a source of electrical energy (a cell or a battery) is connected across a resistor. It maintains a steady current through the circuit. This continuosly supplies energy which is continuously dissipatted in the resistor R of the circuit.

Suppose ΔQ charge passes through any crossection of the circuit in the time Δt. This charge enters the cell at its low potential end and leaves at its higher potential end. The source supply energy ΔW to the positive charge to force it to go to the point of high potential.

So, the amount of energy supplied to unit charge by the cell is called emf E of the source.

$$E = \frac{\Delta W}{\Delta Q}$$

SI Unit of emf is "volt."

$$1 \text{ volt} = \frac{1 \text{ Joule}}{1 \text{ Coulomb}}$$

$$V = JC^{-1}$$

The energy supplied by the cell to the charge carriers comes from the conversion of chemical energy into electrical energy inside the cell.

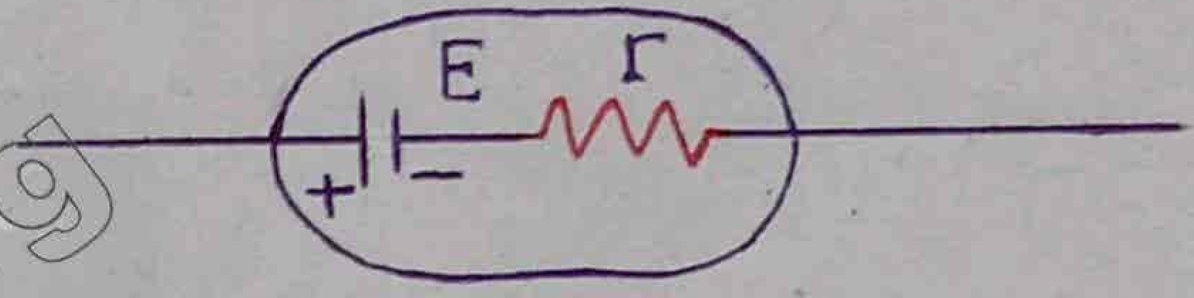
Note:

Electromotive Force is not actually

Force. It is just like potential difference. Hence its unit is Volt.

Internal Resistance (r) of the Cell

"The resistance due to the presence of electrolyte between the two electrodes of the cell is called the internal resistance of the cell."



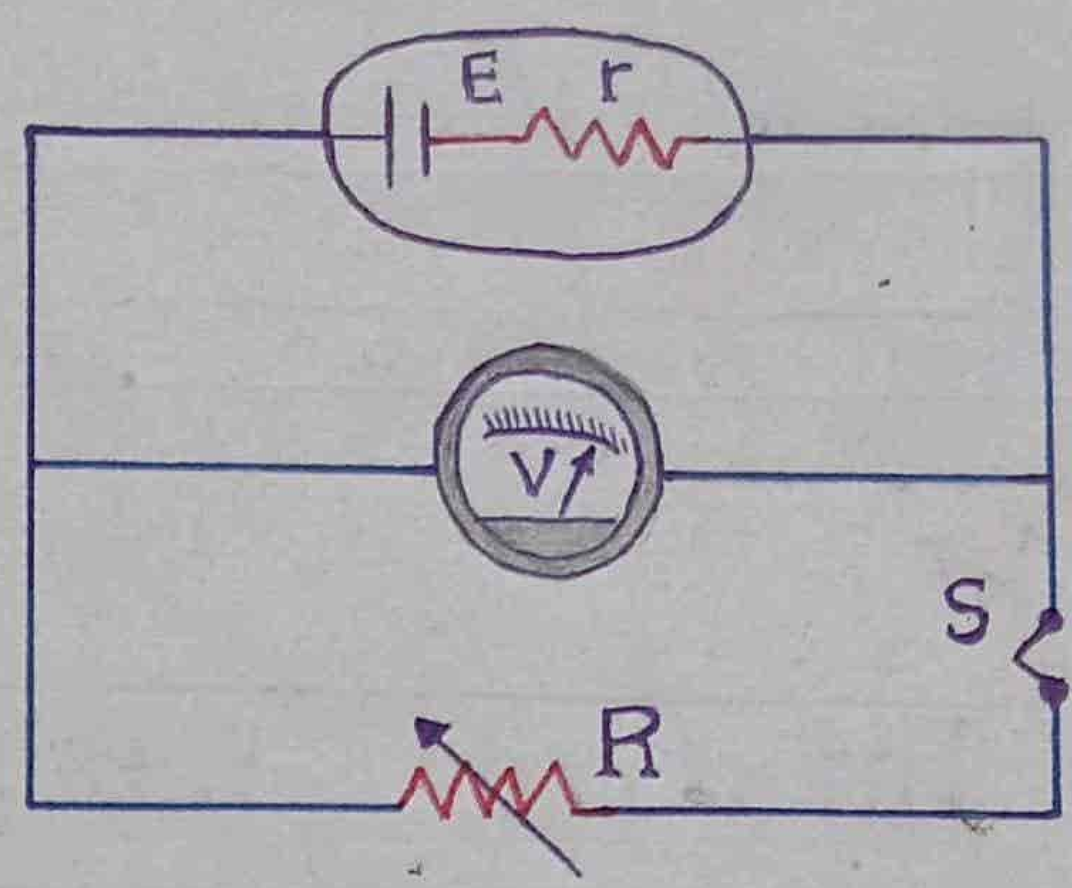
It is denoted by "r".

Terminal Potential difference V = IR

"The potential difference between the terminals of the cell or battery when it is supplying current to the external circuit."

Relation between EMF "E" and terminal potential difference "V":

Now we discuss the performance of a cell of emf E



in the presence of internal resistance "r". See Fig.

A voltmeter of infinite resistance measures the potential difference across the external resistance R or the potential difference V across the terminals of the cell.

Current flowing through the circuit is

$$I = \frac{E}{R + r}$$

Here $R + r$ = Net resistance

$$E = I(R + r)$$

$$E = IR + Ir$$

$IR = V$ is terminal potential difference cell, when current I is flowing in the circuit.

$$E = V + Ir$$

$$V = E - Ir$$

Case-1:

When switch "S" is open, no current passes through the resistance $I = 0$.

$$V = E - Ir$$

$$V = E - (0)r$$

$$V = E - 0$$

$$\boxed{V = E}$$

So,

Voltmeter reads the emf E as terminal voltage.

Case-2:

When switch "S" is closed (on), Current "I" passes through the circuit.

$$V = E - Ir$$

So

$$V < E$$

Hence

The terminal voltage V in the presence of current I is less than emf E by a amount Ir.

It means that potential of the battery is dropped.

Interpretation of Equation $E = IR + Ir$ on the bases of energy conservation:

As $E = IR + Ir$

Multiply by "I"

$$IE = I^2R + I^2r$$

IE = Power supplied by the source of emf **E**.

IE = Energy delivered per second by the source.

I^2R = Power dissipated in the resistance R

I^2R = Energy dissipated per second in resistance R.

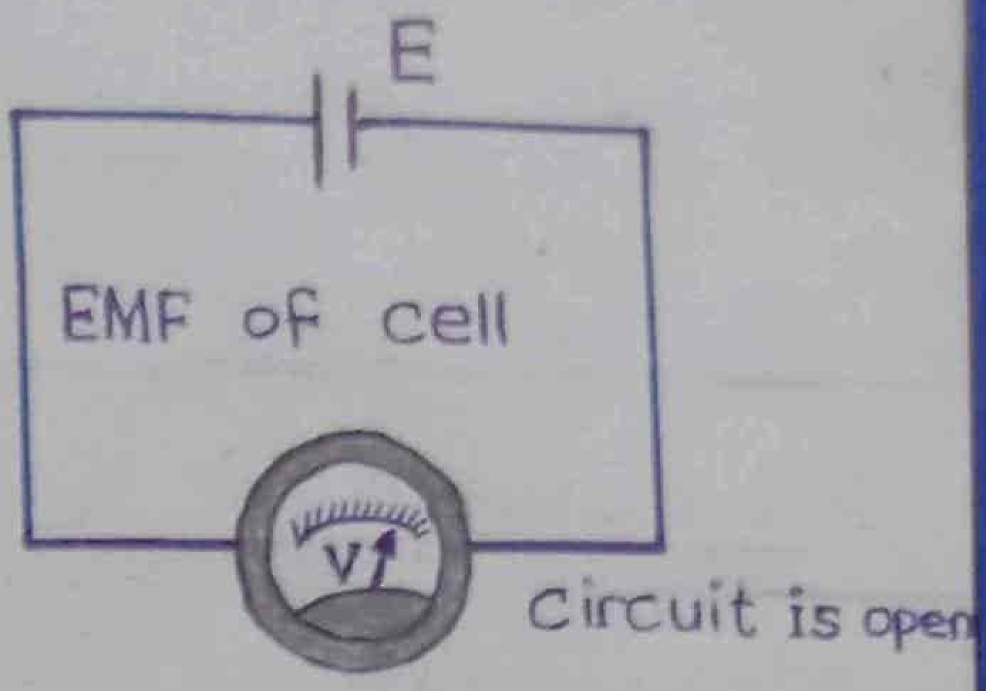
I^2r = Energy dissipated per second in the internal resistance r, inside the cell.

So

Power delivered by battery = Power dissipated in R + Power dissipated in r inside source.

This is in accordance with the Law of conservation of energy.

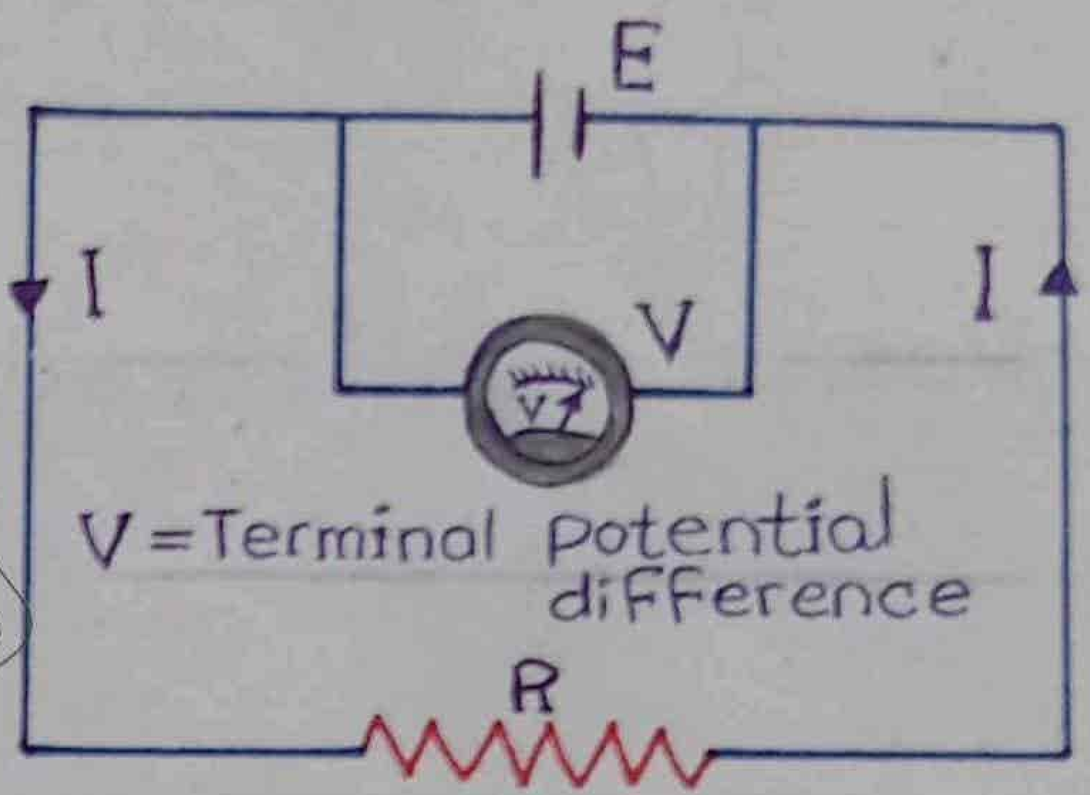
Note that:



V = E

(i) EMF E is the "Cause" and potential difference is the "Effect".

(ii) The emf E is always present even no current is drawn through the battery.



Circuit is closed

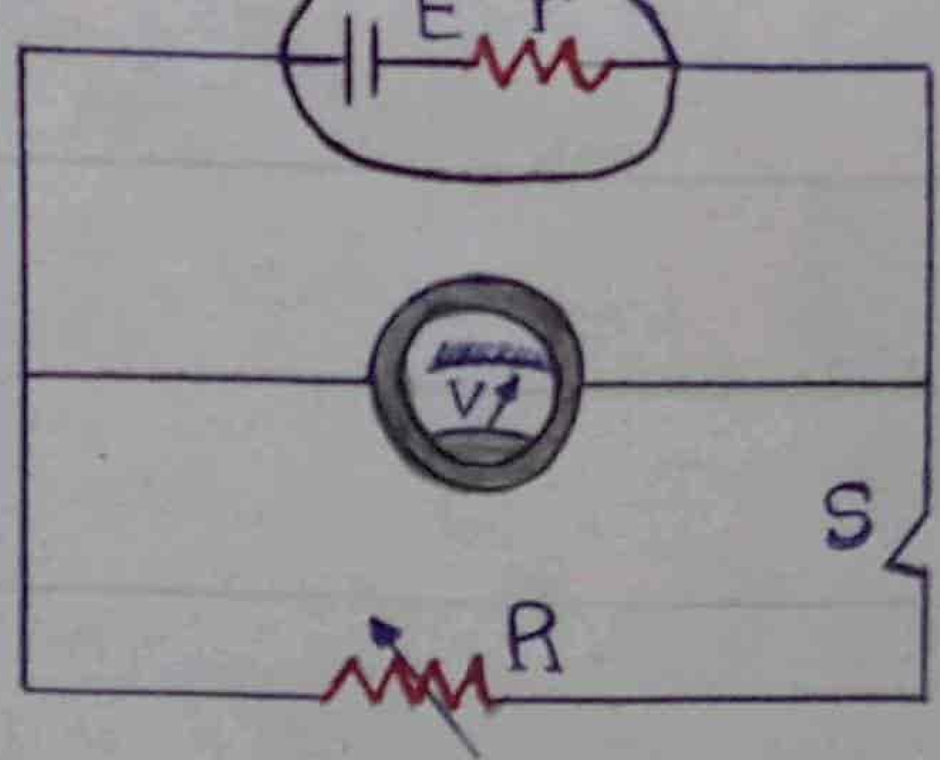
(iii) But the potential difference V across the conductor is zero, when no current flows through it.

$$V = IR$$

$$V = (0)R$$

$$\boxed{V = 0}$$

Maximum Power Output:



When current "I" flows through the resistance R, charges flow from a point of higher potential to point of lower potential. So they loose potential energy.

If V is potential difference across R, the loss of potential energy per second (power) is VI.

This loss of energy per second appears in the other forms of energy and is known as power delivered to "R" by current "I".

Power delivered to R = P_{out} = VI

$$P_{out} = (IR)I$$

$$P_{out} = I^2R \qquad \text{put } I = \frac{E}{R+r}$$

$$P_{out} = \left(\frac{E}{R+r}\right)^2 R$$

$$P_{out} = \frac{E^2R}{(R+r)^2}$$

$$P_{out} = \frac{E^2R}{R^2+r^2+2rR}$$

$$P_{out} = \frac{E^2R}{R^2+r^2+2rR+2rR-2rR}$$

$$P_{out} = \frac{E^2R}{(R^2+r^2-2rR)+4rR}$$

$$P_{out} = \frac{E^2R}{(R-r)^2+4rR}$$

When $R = r$ $(R - r = 0)$ the denominater of the expression of P_{out} is minimum (least). So P_{out} then is Maximum.

$$\text{Max. } P_{out} = \frac{E^2 R}{0 + 4Rr} = \frac{E^2 \cancel{R}}{4\cancel{R}r}$$

$$\boxed{\text{Max. } P_{out} = \frac{E^2}{4r}}$$

Result:

Maximum power is delivered to resistance (load) when the internal resistance of the source r is equal to the load resistance R. $(R=r)$.

$$E_1 \Delta Q - I_1 R_1 \Delta Q - E_2 \Delta Q - I R_2 \Delta Q = 0$$

$\div$ by ΔQ

$$E_1 - IR_1 - E_2 - IR_2 = 0 \quad \text{or} \quad \boxed{\Sigma V = 0}$$

This is Kirchhoff's 2nd Rule and it states that

"The algebraic sum of potential changes for a complete circuit is zero."

Note:

This rule varifies the law of conservation of energy in electrical problems.

Rules for finding the potential changes:

(i) If source of emf is traversed (طے کرنا، گزرنا) from negative to positive terminal, the potential change is positive, it is negative in the opposite direction.

(ii) If a resistor is traversed in the direction of current, the change in the potential is negative, it is opposite in opposite direction.

Procedure of Solution of circuit problems

While using the Kirchhoff's rules for solving the problems it will be helpful to follow the method given below.

1- Draw the circuit diagram.

2- The choice of loops should be such that each resistance is included at least once in the selected loops.

3- Assume a loop current in each loop, All the loop currents should be in the same sense. It may be either clockwise or anti-clockwise.

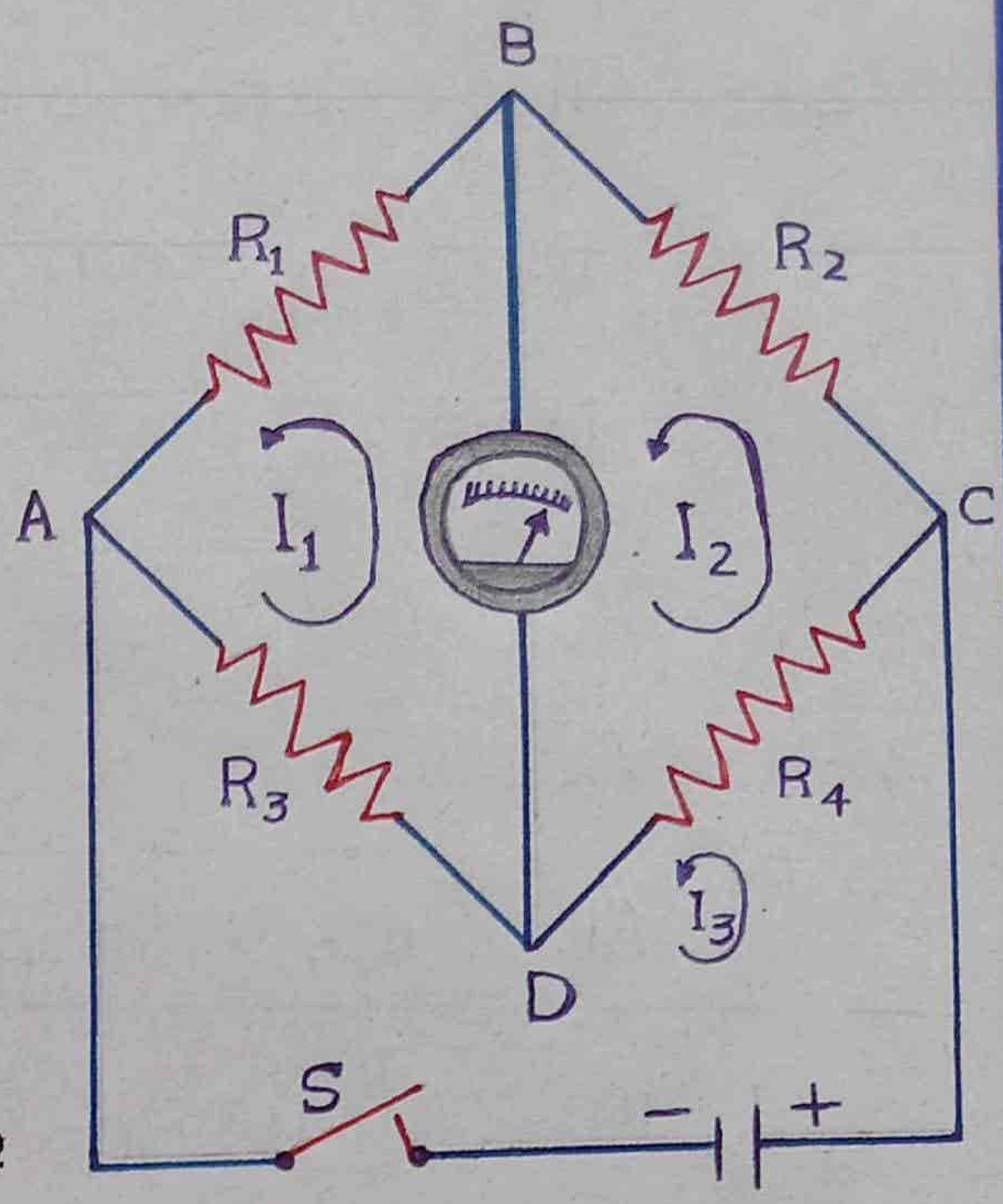
4- Write the loop equations for all the loops. The voltage change across any component is positive if traversed from low to high potential and it is negative if traversed from high to low potential.

5- Solve these equations for unknown quantities.

13.9 Wheatstone Bridge

Wheatstone bridge is a circuit shown in Fig. It consists of four resistances

R_1, R_2, R_3, R_4. They are connected in such a way the circuit forms a Mesh (جال) ABCDA.



A battery is connected between the points "A" and "C". A galvonometer of resistance Rg is connected between the points "B" and "D".

When the switch "S" is closed, a current will flow through the galvonometer.

We consider three loops ABDA, BCDA, ACDA.

We assume anti-clockwise loop currents I_1, I_2 and I in the respective loops.

Apply kirchhoff's 2nd Rule to

1- Loop ABDA:

$$-I_1R_1 - (I_1 - I_2)R_g - (I_1 - I_3)R_3 = 0 \quad \text{—— (1)}$$

2- Loop BCDB:

$$-I_2R_2 - (I_2 - I_3)R_4 - (I_2 - I_1)R_g = 0 \quad \text{—— (2)}$$

The current flowing through the galvanometer will be zero, if

$$(I_1 - I_2) = 0 \quad \text{or} \quad I_1 = I_2 \qquad (I_2 - I_1) = 0$$

Put in equations (1) and (2)

Equation (1)

$$-I_1 R_1 - (0) R_g - (I_1 - I_3) R_3 = 0$$

$$-I_1 R_1 - (I_1 - I_3) R_3 = 0$$

$$-I_1 R_1 = (I_1 - I_3) R_3 \quad \text{———} \quad (3)$$

Equation (2)

$$-I_2 R_2 - (I_2 - I_3) R_4 - (0) R_g = 0$$

$$-I_2 R_2 - (I_2 - I_3) R_4 = 0$$

$$-I_2 R_2 = (I_2 - I_3) R_4$$

Put $I_2 = I_1$

$$-I_1 R_1 = (I_1 - I_3) R_4 \quad \text{———} \quad (4)$$

Divide equation (3) by (4)

$$\frac{-\cancel{I_1} R_1}{-\cancel{I_1} R_2} = \frac{\cancel{(I_1 - I_3)} R_3}{\cancel{(I_1 - I_3)} R_4}$$

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

Whenever this condition is satisfied, no current flows through the galvanometer and it shows:

No Deflection or Zero Deflection (Null Point)

Application:

Let $R_4 = X$ an unknown resistance.

$$\frac{R_1}{R_2} = \frac{R_3}{X}$$

$$X = \frac{R_2}{R_1} \times R_3$$

By adjusting the known values of R_1, R_2, R_3 such that the galvanometer shows no current, then unknown resistance $R_4 = X$ can be found.

13.10 Potentiometer

"An instrument which can (i) measure and (ii) compare potential difference accurately is called potentiometer."

Potentiometer is one of the most accurate methods for measuring potential.

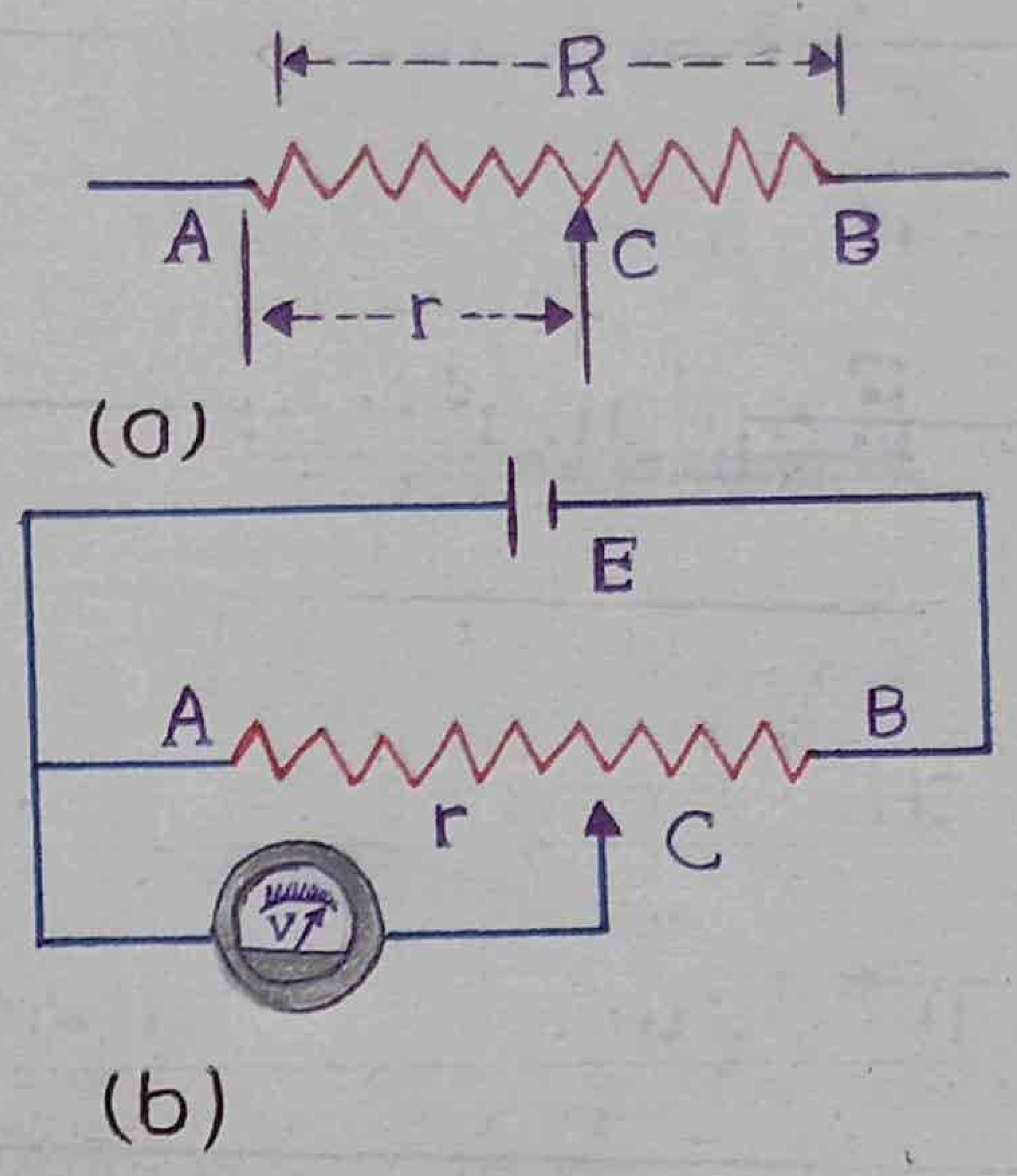
Explanation:

A voltmeter measures potential difference accross a resistor. It cannot measure voltage accurately because it draws some current from the circuit.

An ideal voltmeter has an infinite resistance, so that it could not draw current. The digital voltmeter and Cathode Ray Oscilloscope (CRO) can measure accurate potential difference because they do not draw any current from the circuit. because of their large resistance. But these instruments are very expensive and are difficult to use.

A very simple instument which can measure and compare potential difference accurately is a potentiometer. It draws no current from the circuit.

Constuction:



A potentometer consists of a resistor R in the form of a wire on which a terminal C can slide. Fig (a)

- The resistance between "A" and "C" can be changed from zero to R by moving C from A to B.

- If a battery of emf E is connected across R. Fig (b). Then current flowing through R is

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

- If r = resistance between "A" and "C", then the potential difference between "A" and "C" is

$$V_{AC} = I.r$$

$$V_{AC} = \frac{E}{R} \cdot r$$

$$\boxed{V_{AC} = \frac{r}{R} \cdot E}$$

Working:

As "C" is moved from "A" to "B", r varies from zero to R and the potential drop between A and C changes from zero to E. This arrangement is known as potential divider.

To Measure Unknown EMF of a Cell:

The arrangement of potential divider can be used to measure the unknown emf E_x of a source (cell) using the circuit shown in Fig (c).

A source of potential difference whose emf E_x is to be measured is connected between "A" and the sliding contact C through a galvanometer.

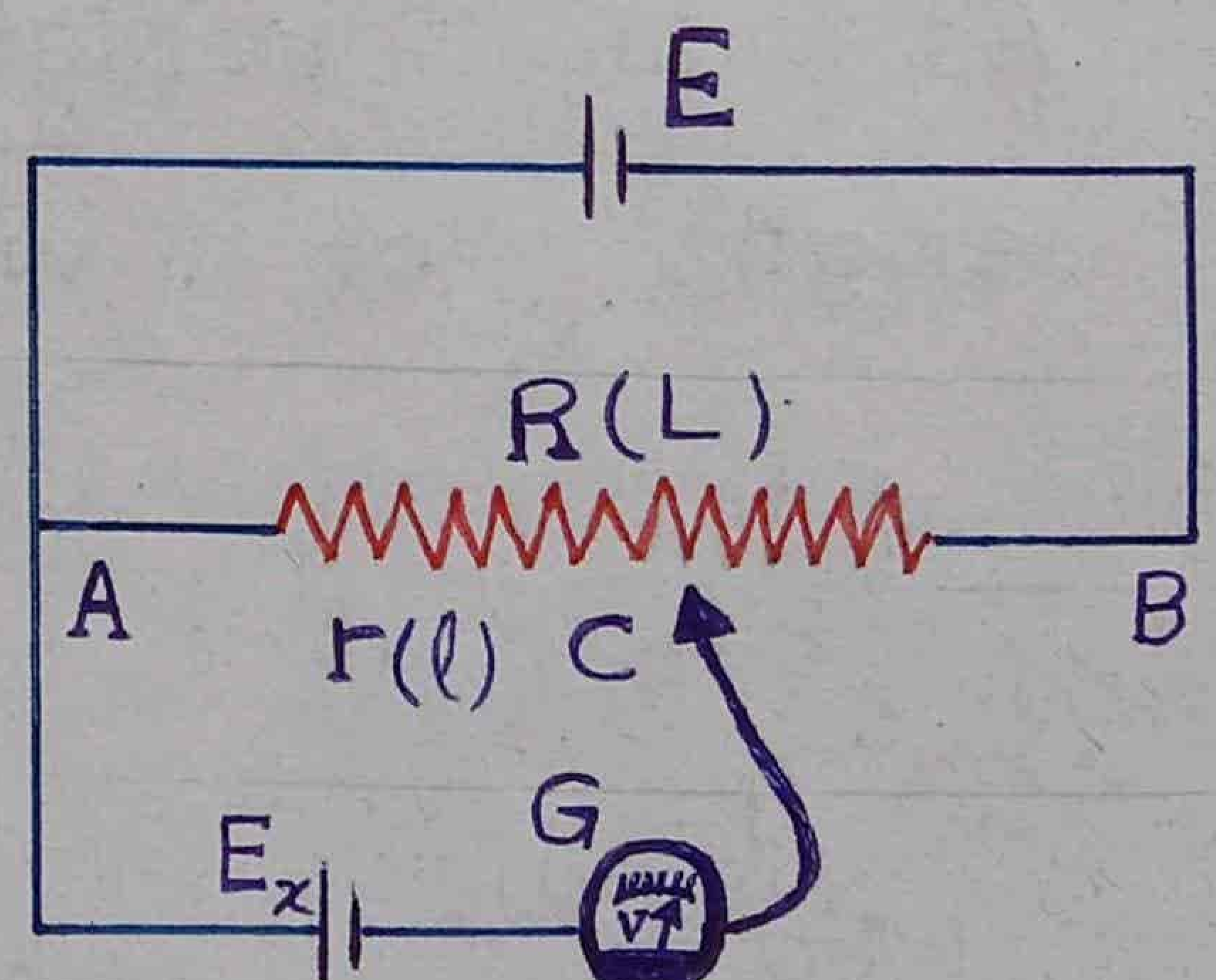


Fig (c)

The positive terminal of E_x and positive terminal of the potential divider are connected to the same point "A".

The sliding contact "C" is so adjusted that galvanometer shows no deplection. It means no current will flow through the galvanometer. Under this condition, the point C and the negative terminal of E_x will be at the same potential.

At this stage, the emf E_x of the cell is equal to the potential difference between "A" and "C".

$$E_x = V_{AC} = E\frac{r}{R} \quad \text{———} \quad (1)$$

As the resistance is proportional to the length of wire

$$r \propto l$$

$$r = \frac{\rho l}{A} \quad \text{———} \quad (2)$$

$$R \propto L$$

$$R = \frac{\rho L}{A} \quad \text{———} \quad (3)$$

Put the equations (2), (3) in (1)

$$E_x = E \frac{\frac{\rho l}{A}}{\frac{\rho L}{A}}$$

$$\boxed{E_x = E \frac{l}{L}}$$

L = Total length of the wire AB

l = length of the wire between "A" and "C".

Knowing the values l, L, E.

So E_x can be found.

Note:

The unknown emf E_x should not exceed E value, otherwise the null condition will not be obtained.

$$E_x \leq E \quad ; \quad E_x \not> E$$

To compare EMF's E_1 and E_2 of two cells:

The method for measuring the emf of a cell can be used to compare the emf's E_1 and E_2 of two cells. The balancing lengths l_1 and l_2 are found seperately for the two cells. Then

$$E_1 = E\frac{l_1}{L}$$

$$E_2 = E\frac{l_2}{L}$$

Dividing E_1 by E_2

$$\frac{E_1}{E_2} = \frac{E\frac{l_1}{L}}{E\frac{l_2}{L}}$$

$$\boxed{\frac{E_1}{E_2} = \frac{l_1}{l_2}}$$

Result:

Ratio of the emf's is equal to the ratio of balancing lengths.

Answers of the Short Questions

13.1 A potential difference is applied across the ends of a copper wire what is the effect on the drift velocity of free electrons by

(i) Increasing the potential difference

(ii) Decreasing the length and temperature of wire

13.2 Do bends in a wire affect its electrical resistance? Explain.

13.3 What are the resistances of the resistors given in the figures A and B? What is the tolerance of each? Explain what is meant by the tolerance?

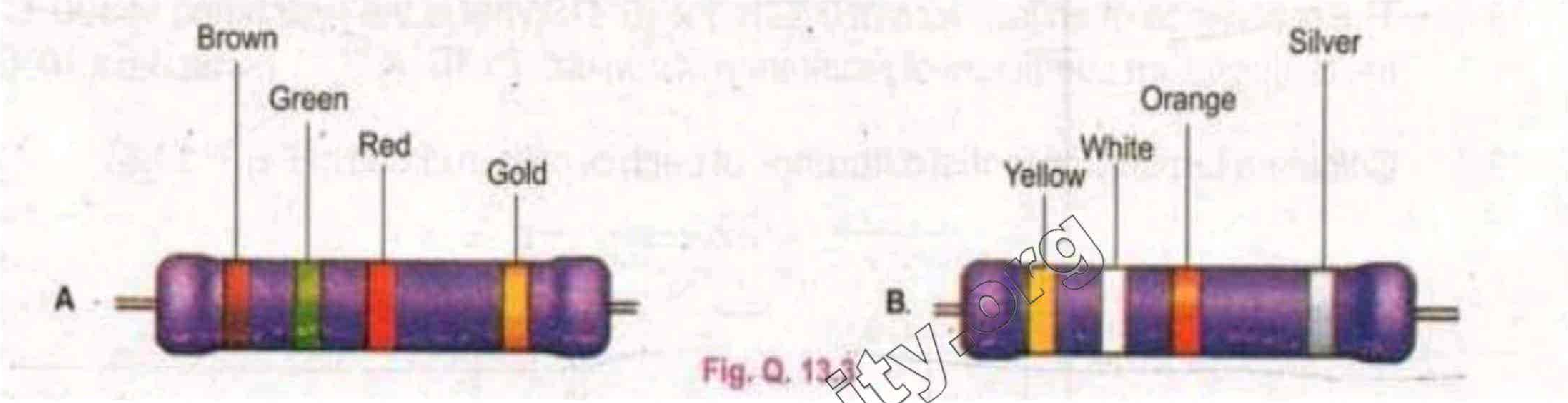


Fig. Q. 13.3

13.4 Why does the resistance of a conductor rise with temperature?

13.5 What are the difficulties in testing whether the filament of a lighted bulb obeys Ohm's law?

13.6 Is the filament resistance lower or higher in a 500 W, 220 V light bulb than in a 100 W, 220 V bulb?

13.7 Describe a circuit which will give a continuously varying potential.

13.8 Explain why the terminal potential difference of a battery decreases when the current drawn from it is increased?

13.9 What is Wheatstone bridge? How can it be used to determine an unknown resistance?

Answers of Short Questions

Q-13.1:

(i) As $V = Ed$

$V \propto E$ If d = constant

Increasing the potential difference "V" will increase "E".

As

$$F = qE$$

$$F \propto E$$

If E increases, Force F on electrons also increases. Hence

Drift velocity will increase.

(ii)

As $V = Ed$ or $E = \frac{V}{d}$

$$E \propto \frac{1}{d}$$

$d = L$ = length of the wire.

$$E \propto \frac{1}{L}$$

If length of the wire L decreases,

E increases.

$$F = qE$$

$$F \propto E$$

By increasing "E" Force on the electrons increases. Hence

Drift velocity increases.

* By decreasing the temperature, the amplitude of the vibration of atoms decreases. So, the chance of collisions of free electrons with atoms decrease. Hence,

the drift velocity increases.

Q-13.2: As

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

$$R \propto L$$

$$R \propto \rho$$

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

As, electrical resistance of a wire depends on its

(i) Nature

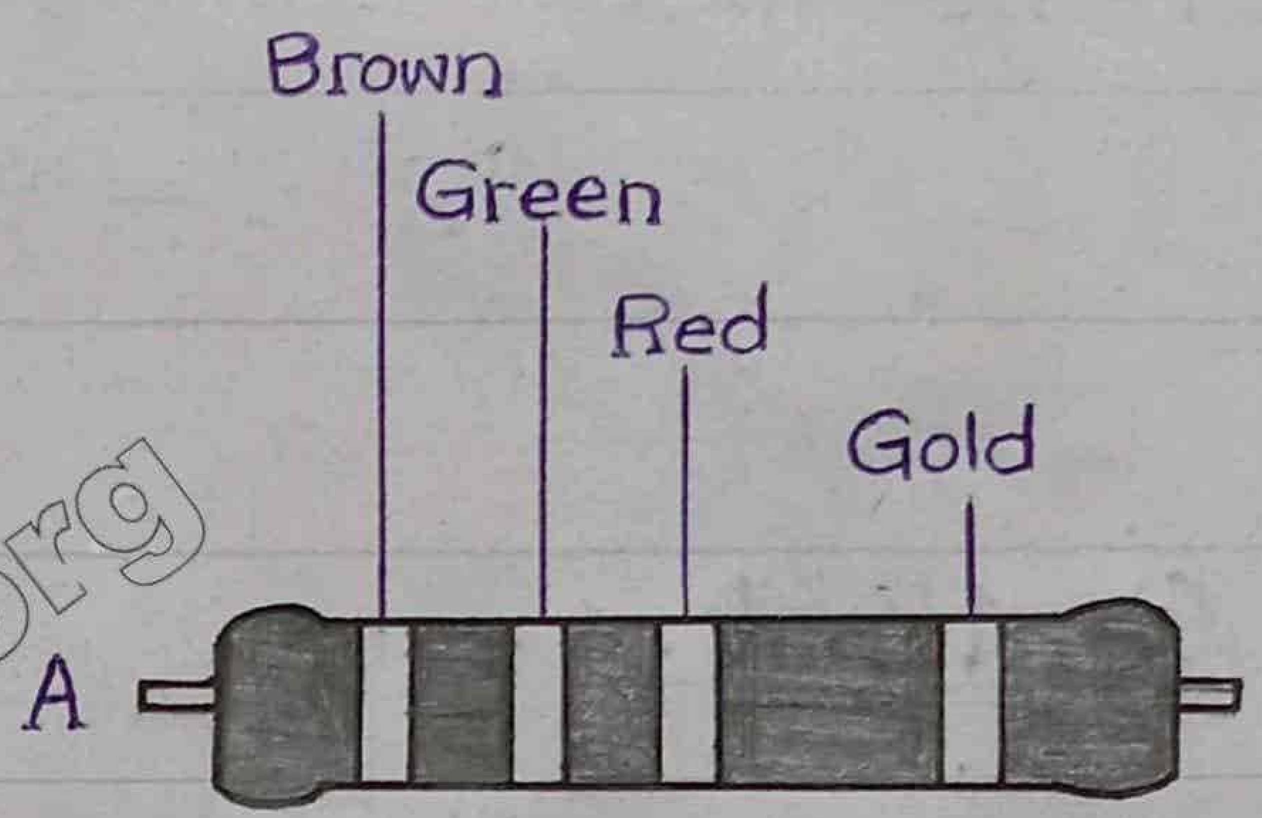
(ii) Length

(iii) Area of crossection

So,

Bends in a wire do not have any affect on its length, area and nature of wire. So Resistance is not affected.

Q-13.3:



1st Band (Brown) = 1

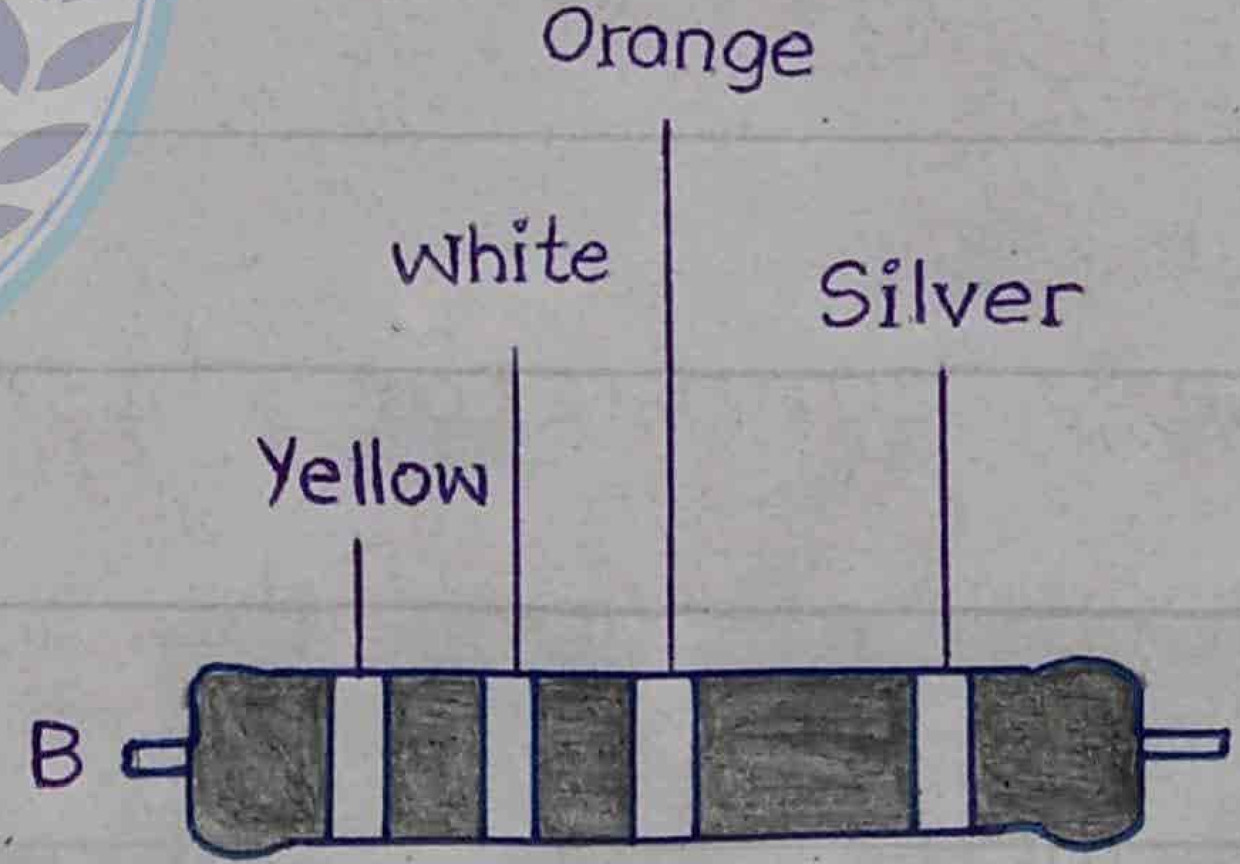
2nd Band (Green) = 5

3rd Band (Red) = 00

4th Band (Gold) = 5% (Tolerance)

So

$$R = 1500\,\Omega \pm 5\,\%$$



1st Band (Yellow) = 4

2nd Band (White) = 9

3rd Band (Orange) = 000

4th Band (Silver) = 10%

So

$$R = 49000\,\Omega \pm 10\,\%$$

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Tolerance:

"Tolerance means the possible variation of resistance from the given value."

Example:

A 1000 ohm resistance with a tolerance of ±10 % will have an actual resistance anywhere between 900 Ω to 1100 Ω.

$$R = 900\,\Omega \leftrightarrow 1100\,\Omega .$$

Q-13.4:

Effect of temperature on Resistance

The resistance offered by a coductor to the flow of electrons is due to the continuous collision of free electrons with the atoms.

As the temperature of the conductor is increased, the amplitude of vibration of the atoms increases. So, the chances of collisions of free electrons with the atoms also increases.

Hence

"By increasing the temperature of

a metallic conductor, Resistance of the conductor also increases.

Q-13.5:

The heated Filament of a lamp does not obey Ohm's Law.

Reason:

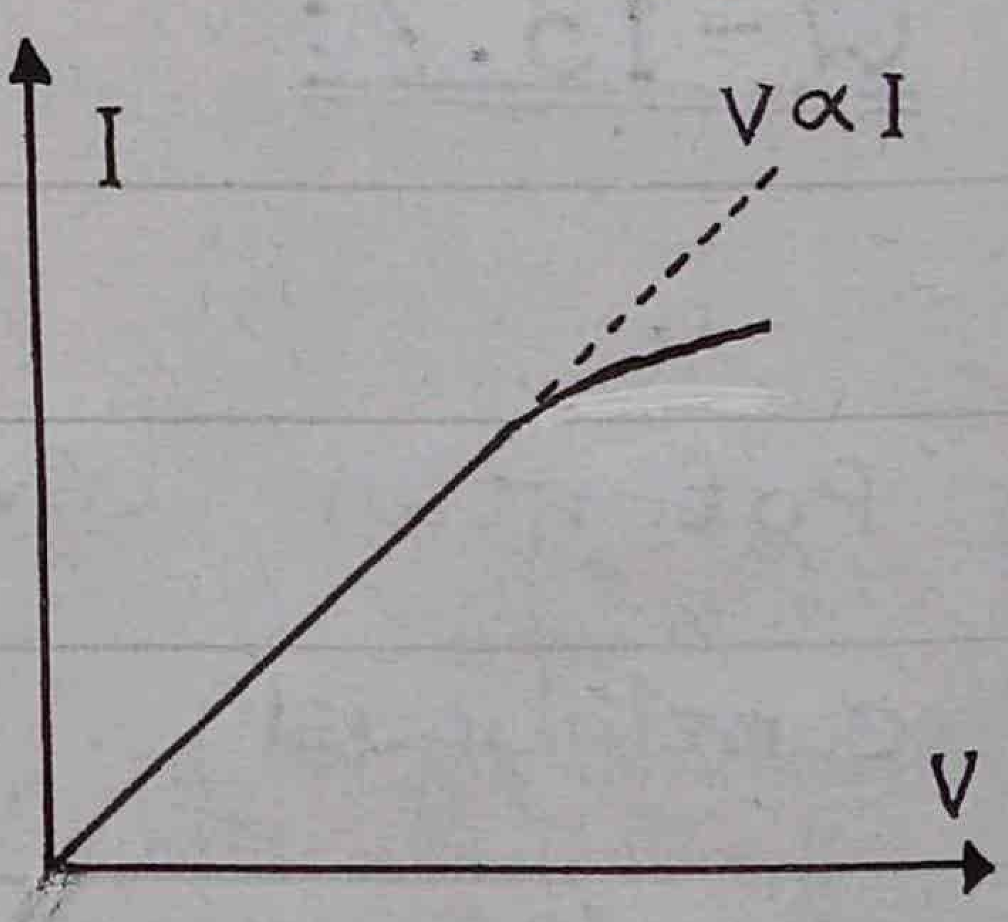
According to Ohm's Law

$$V \propto I$$

$$V = IR$$

Hence, R = Resistance of the conductor remains constant.

As the current "I" is increased, heat energy H ($H = I^2Rt$) is produced. This increases the resistance of the Filament. Hence the current "I" increases at a lower rate.



Hence it does not ohm's Law.

Q-13.6:

The power dissipated in a resistor

is given by

$$P = \frac{V^2}{R} \qquad \text{If } V = \text{constant}$$

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

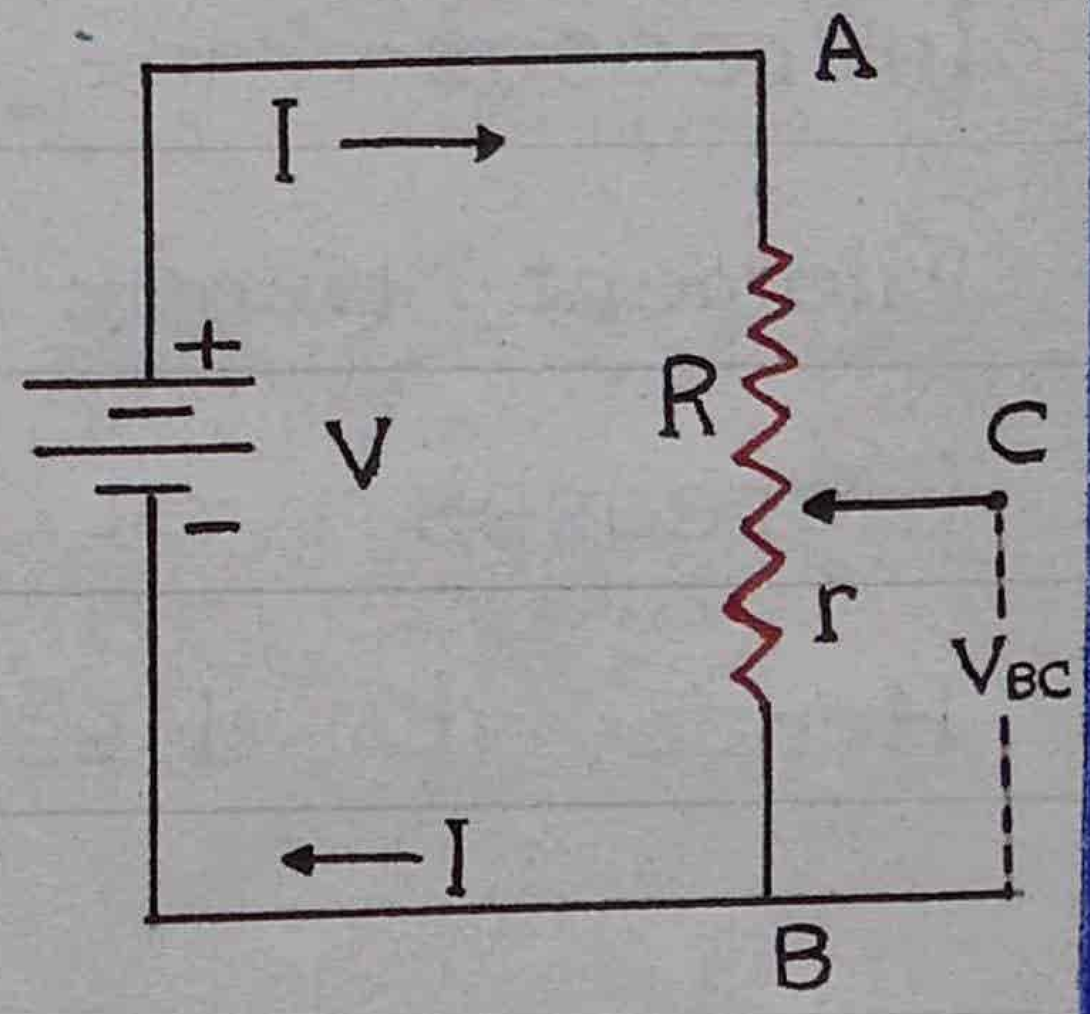
$$R \propto \frac{1}{P}$$

So, more powerfull bulb has smaller resistance. Hence, resistance of $P = 500$ Watt bulb is smaller than $P = 100$ Watt bulb.

$$R_{500\ \text{watt bulb}} < R_{100\ \text{watt bulb}}$$

Q-13.7:

Potential divider:



Potential divider can provide continuously varying potential. circuit is shown in Figure. Battery provides voltage "V" across the points A, B of the rheostat. The current through the resistance R is

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

V_{BC} = Potential difference between the points "B" and "C" is

$$V_{BC} = Ir$$

$$V_{BC} = \left(\frac{V}{R}\right) r$$

$$\boxed{V_{BC} = \frac{r}{R} V}$$

1) When C is moved towards the end B, the resistance of the wire "r" decreases. Hence V_{BC} decreases.

2) When C is moved towards the end "A", the resistance of the wire "r" increases. Hence V_{BC} increases.

So, V_{BC} can be varied from "0" to "V" volts.

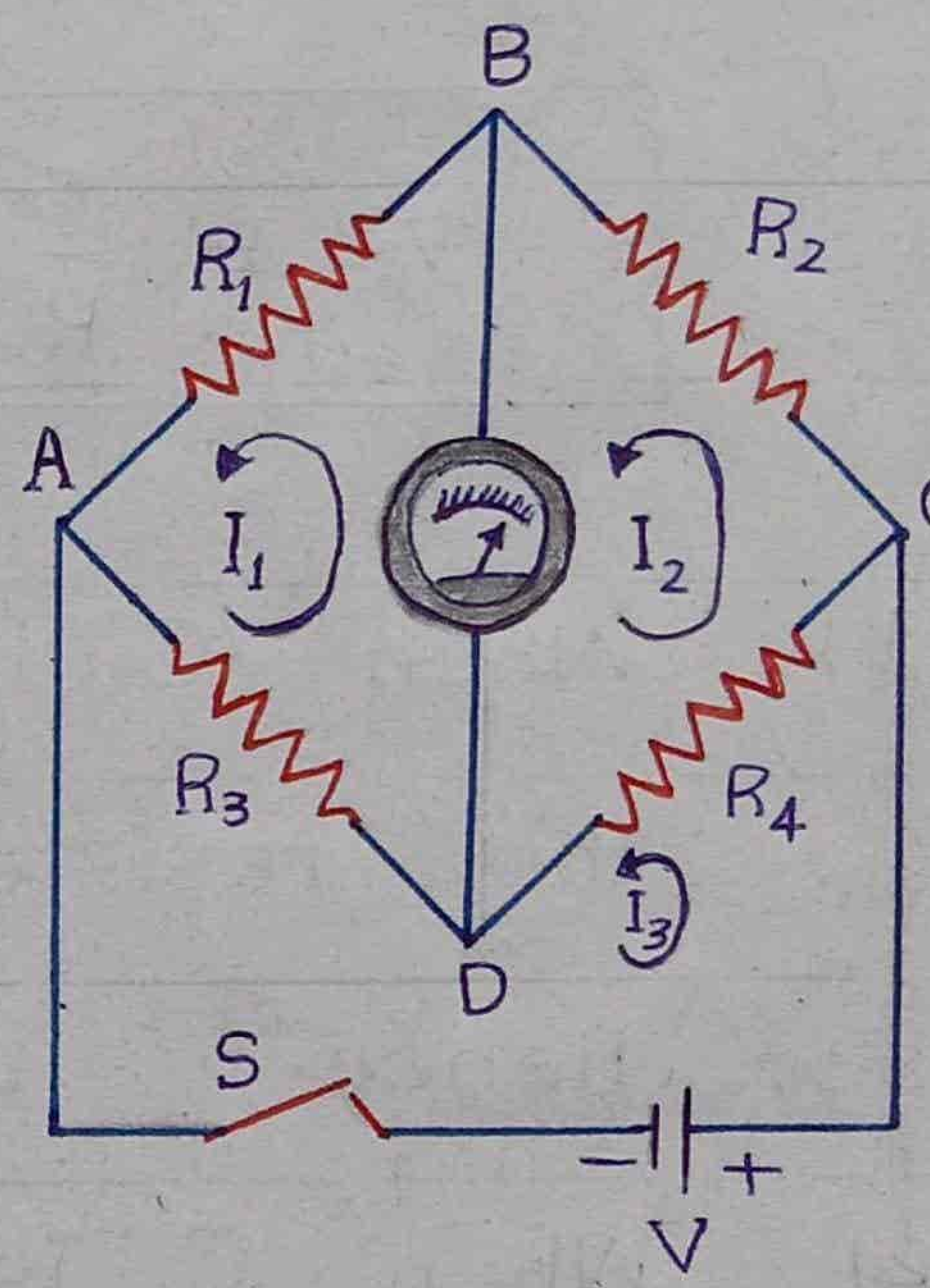
Q-13.8:

The terminal potential difference "V" of a battery is related to its EMF "E" by $$V = E - Ir$$

When the current "I" increases, the potential difference "Ir" across the internal resistance increases. Because EMF "E" is constant, the terminal potential difference "V" of the battery decreases.

Q-13.9:

Wheatstone Bridge



It consists of four resistances R_1, R_2, R_3, R_4 connected in such a way to form a mesh (جال) ABCDA. When the bridge is balanced electrically no current flows through the galvanometer. In this situation

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

If $R_4 = X$ = unknown resistance

$$\frac{R_1}{R_2} = \frac{R_3}{X} \quad \text{or} \quad X = \frac{R_2}{R_1} \times R_3$$

Knowing the values of R_1, R_2, R_3, the unknown resistance X can be found.