ELECTRICITY

Electrostatic Potential: When electric charges move through a conductor, an electric field interacts with the moving charges and hence some energy is spent in moving the charges in forward direction. The measure of the energy spent is called the electrostatic potential. Thus, the electrostatic potential at any point may be defined as the work done in bringing a unit positive charge from infinity to that point. It is denoted by the letter "V" and is measured in Volt. Thus a potential is said to be 1 Volt if 1 joules of work is done in bringing a charge of 1 coulomb from infinity to that point.

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 another in an electric circuit. If "W" be the amount of work done in moving "Q" coulomb of charge from one point to another , then potential difference "V" between two points is given as;

$$\text{Pot. Difference} = \frac{\text{Work done}}{\text{Quantity of charge transferred}} \Longrightarrow \mathbf{V} = \frac{W}{Q}$$

Measurement of potential difference: The potential difference is measured by an instrument called as voltmeter. It is connected in parallel with the circuit. An ideal voltmeter should have a high resistance so that it takes a negligible current from the circuit.

Units of potential difference:- The S.I. unit of potential difference is Volt. The potential difference between any two charges is said to be one volt if work of 1 joule is done in moving 1 coulomb of charge from one point to another i.e.

$$1\text{ Volt} = \frac{1\text{ joule}}{1\text{ coulomb}} \Longrightarrow \mathbf{1V} = \frac{1J}{1C}$$

Electric current: The flow of electric charge through a conductor is called as electric current and the magnitude of electric current is the amount of electric charge passing through a given point of conductor in one second .

Consider a charge of "Q" coulombs flowing though a conductor in time "t" seconds, then the magnitude of electric current flowing through the conductor "I" can be given as under,

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

The S.I. unit of electric current is Ampere denoted by letter "A". Current is said to be one ampere if a charge of 1 coulomb flows through any conductor in one second, i.e

$$1\text{ ampere} = \frac{1\text{ Coulomb}}{1\text{ second.}}$$

Measurement of Current: Current flowing through a circuit is measured by an instrument called as ammeter. It is connected in series with the circuit in which the current is to be measured. An ideal ammeter should have a very low Resistance (shunt) so that it may not change the value of electric current flowing in the circuit.

Relationship between Potential difference and Current Or Ohm's Law:

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" be the current flowing through a conductor and "V" the Potential difference across its ends, then according to the Ohm's law,

$$\mathbf{I \;\alpha\; V}$$

Or $$\mathbf{V \;\alpha\; I}$$

Or $$\mathbf{V = R.I}$$

Where "R" is constant of Proportionality and is called as resistance of a conductor.

$$\Longrightarrow \quad \mathbf{\frac{V}{I} = R}$$

Or $$\mathbf{V = IR}$$

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

Thus from above equation it is quite clear that the current flowing through a conductor "I" is directly proportional to its Potential difference "V" and inversely proportional to the resistance "R".

Experimental Verification Of Ohm's Law:

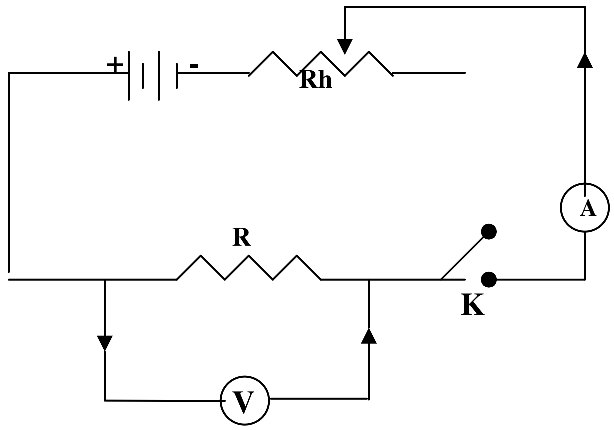
The circuit diagram for the verification of Ohm's Law is as shown as under:

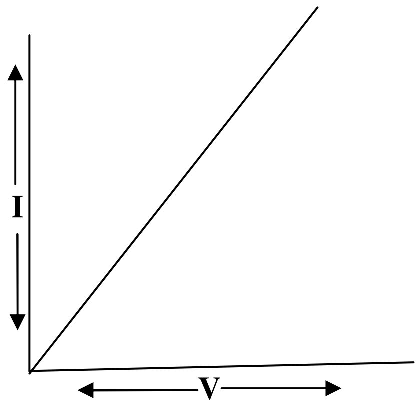
In this circuit a conductor having resistance "R" is connected in series with an ammeter "A", battery "B", key "K" and a rheostat "Rh". The voltmeter "V" is connected across the conductor to measure the voltage .The Ammeter measures the current through the resistance "R". The purpose of rheostat is to change the circuit resistance and hence current .The key "K" is to make or break the circuit.

To start the experiment, close the key "K" and set the rheostat "Rh" at some value .Take the reading of voltmeter "V" and ammeter "A". Let it be V_1 and I_1 respectively. Find the ratio of V_1/I_1.Now change the setting of rheostat so that current in the circuit changes. Note down the readings again. Let it be V_2 and I_2 respectively. Find the ratio of $V_2$and I_2.It will be found that

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

On taking a number of readings , it is observed that the ratio of potential difference to current in each case is constant and is equal to the resistance of the conductor .If we plot a graph between the voltage and current ,a straight line is obtained, which also proves the Ohm's law.





Resistance of a Conductor: Resistance of a conductor is defined as the property due to which it opposes the flow of current through it . It is defined by letter "R" and is equal to the ratio of potential difference across its ends to the current flowing through it.

Thus,

$$\text{Resistance} = \frac{\text{Potential Difference}}{\text{Current}}$$

$$\text{Or} \quad \mathbf{R} = \frac{\mathbf{V}}{\mathbf{I}}$$

The S.I. Unit of resistance is Ohm denoted by Greek symbol Omega(Ω).The Resistance of a conductor is said to be 1 Ohm if a potential difference of 1 volt is applied across its ends and a current of 1 ampere is flowing through it, i.e

$$1 \text{ Ohm} = \frac{1 \text{ Volt}}{1 \text{ Ampere}}$$

Factors on which Resistance of a conductor depends:

Resistance of a conductor depends upon:

a) Length:- If the length of a conductor increases, the electrons have to travel a longer distance and as a result fo this, its resistance increases. If 'l' is the length of the conductor then

Thus, $R \propto l$ …………………… (1)

b) Cross-Sectional area:- If the cross-sectional area of the conductor decreases, the electrons find it more difficult to pass through it and as such its resistance increases. Thus.

$$R \propto \frac{1}{A} \quad \text{…………………… (2)}$$

Combining 1 and 2, we get

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

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

Where $\mathcal{P}$ is a constant of proportionality and is called the specific resistance or resistivity of the conductor. The resistivity of conductor depends on the nature of its material.

<u>Resistivity:-</u> Resistivity of a material is defined as the resistance offered by a cube of the material of side one metre when the current flows perpendicular to the opposite faces of the cube. It is defined as the resistance of the conductor of length 1m having area of cross-section $1m^2$.

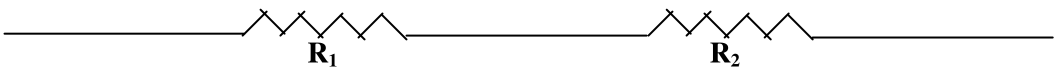
<u>Unit of Resistivity:-</u>

We know that $R = \frac{Pl}{A}$, $\mathcal{P} = \frac{RA}{l}$

Unit of P is $\frac{ohm \times m^2}{m} = ohm - m$

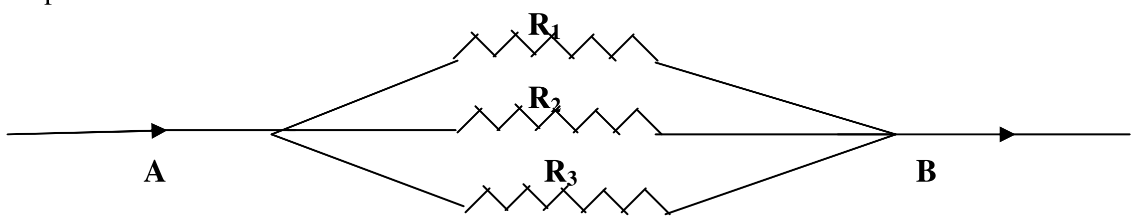
<u>Combination of Resistance:</u> The Resistance can be combined in two ways in electrical circuit viz.

<u>I) In Series:</u> When two or more resistance are connected end to end consecutively, they are said to be connected in series as shown under:



The current flowing through each resistances placed in series remains same.

<u>II) In Parallel:</u> When two or more resistances are connected between the same two points, they are said to be connected in parallel as shown under:



The potential difference across the ends of each resistance remains same.

<u>Law of Combination of Resistances:</u>

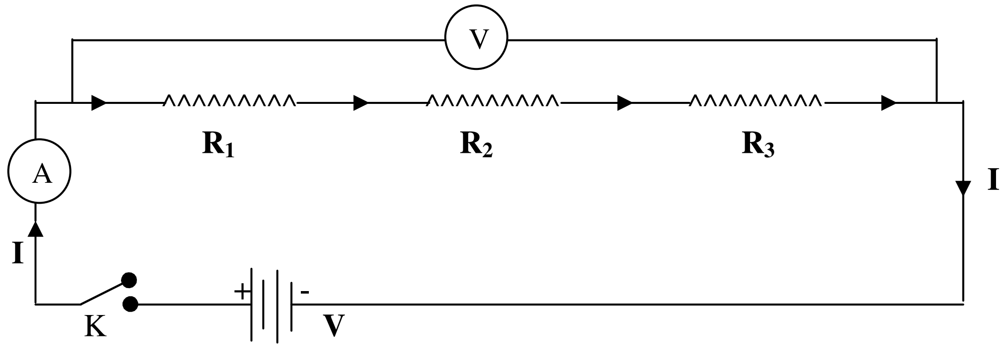
<u>1) Law of combination of resistances in series:</u>

According to this law, "The combined resistance of any number of resistances connected in series in a circuit is equal to the sum of their individual resistances". For example if a number of resistances $\mathbf{R_1}$, $\mathbf{R_2}$, $\mathbf{R_3}$, $\mathbf{R_4}$**--------**$\mathbf{R_n}$ are connected in series, then their resultant resistance is given by.

$$\mathbf{Rs = R_1 + R_2 + R_3 + R_4 \text{ -------------- } R_n}$$

Expression for total resistance of a number of resistances connected in series:

Consider three resistances R_1, R_2 and R_3 connected in series as shown under in the figure.



Let "V" be the total voltage applied across the ends and "I" be the total current flowing through the circuit. Then, according to the Ohm's law, we have:

$$V = I \, . \, R_s \qquad [\text{because } R = \frac{V}{I}]$$

Therefore, Voltage drop across resistance R_1, can be given as:

$$V_1 = I \, . \, R_1 \quad \text{-------------------- (i)}$$

And Voltage drop across resistance R_2, can be given as:

$$V_2 = I \, . \, R_2 \quad \text{------------------ (ii)}$$

And Voltage drop across resistance R_3, can be given as:

$$V_3 = I \, . \, R_3 \quad \text{------------------ (iii)}$$

Since total voltage applied on the circuit is V, then:

$$V = V_1 + V_2 + V_3$$

$$\Rightarrow \quad V = I R_1 + I R_2 + I R_3 \quad \text{(Using Eq.s i, ii and iii)}$$

$$\Rightarrow \quad V = I (R_1 + R_2 + R_3)$$

$$\Rightarrow \quad V / I = R_1 + R_2 + R_3$$

But, from Ohm's law, we have:

$$V / I = R$$

Then $\vec{R} = R_1 + R_2 + R_3$

Hence, the total resistance of a no. of resistances connected in series in a circuit is given by the algebraic sum of their individual resistances.

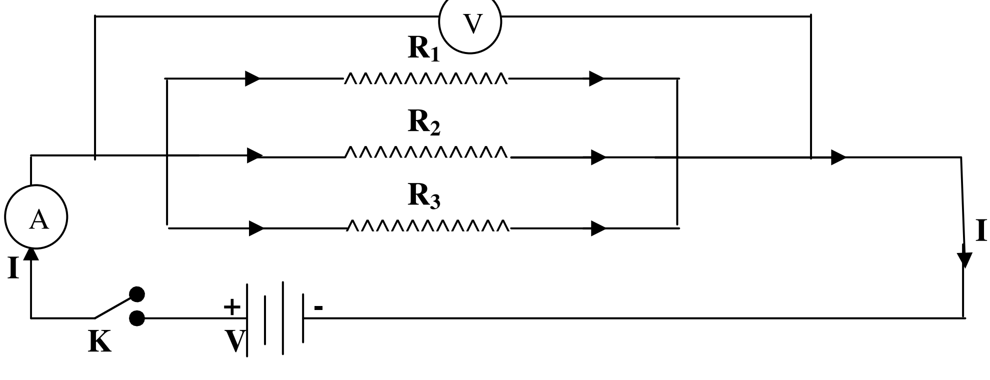
2) Law of Combination of resistances in Parallel:

According to this, "The Reciprocal of the combined resistances of a number of resistances of a number of resistances connected in parallel is equal to the sum of the reciprocal of all the individual resistances". If a number of resistances **R_1, R_2, R_3, R_4--------R_n are** connected in parallel, then their combined resistance **R** is given as under:

$$\mathbf{1/\vec{R} = 1/R_1 + 1/R_2 + 1/R_3 + 1/R_4 \text{------------------------} 1/R_n}$$

Expression for total resistance of a number of resistances connected in parallel:

Consider three resistances R_1, R_2 and R_3 connected in parallel as shown under in the figure:



Let "V" be the total voltage applied across the ends and "I" be the total current flowing through the circuit. Then according to Ohm's Law, we have:

$$\mathbf{V = I \, . \, R \qquad \Rightarrow \quad I = V / R}$$

Therefore, current across resistance R_1 can be given as: $\mathbf{I_1 = V / R_1}$ **…………..(I)**

Similarly, current across resistance R2 can be given as: $I_2 = V / R_2$ ……………(II)

And, current across resistance R_3 can be given as: $I_3 = V / R_3$ ……………(III)

Since total current flowing current flowing through the circuit is I, then:

$$I = I_1 + I_2 + I_3$$

$$\Rightarrow \quad I = V / R_1 + V / R_2 + V / R_3 \quad \text{[Using equations (I), (II) \& (III)]}$$

$$\Rightarrow \quad I = V \ (1 / R_1 + 1 / R_2 + 1 / R_3)$$

$$\Rightarrow \quad I / V = 1 / R_1 + 1 / R_2 + 1 / R_3$$

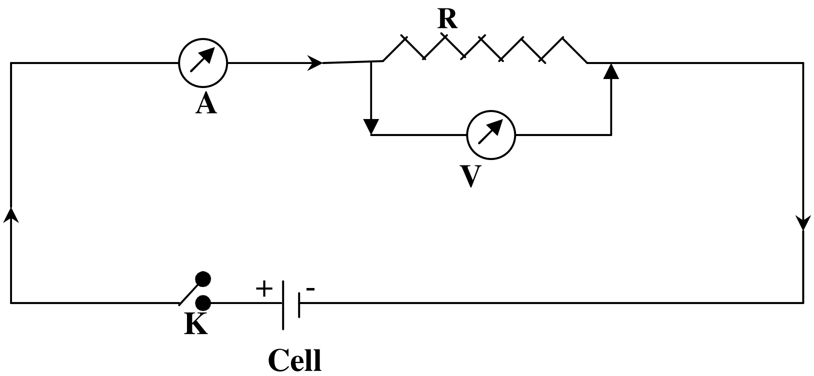
But from Ohm's Law, we have:

$$V / I = R_p \quad \Rightarrow \quad I / V = 1 / R$$

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

Hence the reciprocal of the total resistance of a number of resistances connected in parallels in a circuit is given by the algebraic sum of the reciprocals of the individual resistances.

Electrical Circuits: A circuit may be defined as a continuous path of conducting wires and other resistances between the terminals of a battery along which an electric current is flowing .Drawing circuit diagrams, showing the connectivity of the different components of a circuit by using their electrical symbols, represents these. A circuit containing resistance "R", Voltmeter "V", ammeter "A", key "K" and cell connected together is shown under:



Electric Power: When an electric current flow through a conductor, electrical energy is used up and it is said that current is doing work. The rate of doing work is called as power. In other words, electric power is the work done by electrical current in unit time. Thus.

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}}$$

If "W" be the work done by the electrical current in time "t" seconds then the power "P" can be given as under:

P = W/t------------------------------ (I)

But W = V x I x t **[because W = Vq and q = It]**

Where V = Potential difference
I = Current flowing
t = Time taken

Thus $$P = \frac{V \times I \times t}{t}$$

Or P = V x I ------------------------- (II)

Thus,

Electric power = Potential difference x current

Also from Ohm's law, we have;

V/I =R

Or **V = I.R**

∴ From equation and we have

P = I x R x I

P = I^2R ------------------------- (III)

But from Ohm's law

I = V/R

Then from equation II we have

P =V x I

Or **P = V x V/R**

Or **P = V^2/R---------------------- (IV)**

Thus, from equation (I) (II) (III) and (IV) are four equation for explaining and calculating electrical power.

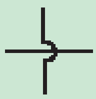
Thus S. I. unit of electrical power is watt denoted by letter "W" and power is said to be 1 watt if a work of 1 joule is done in one second.

$$\textbf{1 watt} = \frac{\textbf{1 joule}}{\textbf{1second}}$$

However, power can also be expressed in bigger units like kilowatts and Megawatts;

When, I Kilowatt $=10^3$ watts.

And 1 Megawatt $= 10^6$ watts

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

Electric Energy: When an electrical current flow through a conductor, work is being done by the electrical current and the electrical energy consumed is given by the product of electric power and the time for which it is consumed i.e.

Electric energy = Power x time

E = P x t

But **P** **= Vx I**

Thus **E** **= V x I x t**

Or **E** **= VI t**

Thus, the product of voltage, current and time, can give electrical energy consumed. The S.I unit of energy is Joule. When a joule is the amount of electrical energy consumed when an appliance of 1 Watt power is use for one second. However a bigger unit of electrical energy is Kilowatt-hour also known as Board of trade unit (B.T.U).

Joule's Law of Heating:-

Consider a current 'I' flowing through a resistor of resistance R. Let the potential difference across it be V. Let the time during which a charge Q flows across. The work done is 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

$$P = \frac{VQ}{t} = VI$$

Or the energy supplied to the circuit by the source in time t is P x t, i.e. VIt
Thus for a steady current I, the amount of heat H produced in time t is

$$H = VIt$$

Applying Ohm's law, we get

$$H = I^2Rt$$

This is known as Joule's law of heating.
This law implies that, heat produced in a resistor is:

1. Directly proportional to the square of current for a given resistance.
2. Directly proportional to resistance for a given current and
3. Directly proportional to the time for which the current flows through the resistor.

Heating effect Electric Current:-

Whenever a current is passed through a conductor, it becomes hot. This means that electric energy is being converted into heat energy. This is called the heating effect of current.

We know that conductors have free electrons. When a potential difference is applied across the ends of a conductor, these electros begin to drift from lower potential to higher potential. The motion of these electrons is not smooth because they experience a resistance on account of their collisions with other electrons and also with the ions in the conductor. As a result of this, some work is done to overcome this resistance. It is this work done that is converted into heat.