ELECTRICITY

EDUMAX CLASSES
EDUCATION AT MAXIMUM

1. Introduction

Physical phenomena associated with the presence and flow of electric charge is known as electricity. Electricity and electrical phenomenon have a lot of applications in our day to day life and they also gives a wide variety of well-known effects, such as lightning, static electricity, electromagnetic induction and the flow of electrical current.

- Electricity occurs due to several types :

  1. **Electric charge:** a property of some subatomic particles, which determines their electromagnetic interactions.
  2. **Electric current:** a movement or flow of electrically charged particles, typically measured in amperes.
  3. **Electric field:** an especially simple type of electromagnetic field produced by an electric charge even when it is not moving (i.e., there is no electric current). The electric field produces a force on other charges in its vicinity. Moving charges additionally produce a magnetic field.
  4. **Electric potential:** the capacity of an electric field to do work on an electric charge, typically measured in volts.

Fractional electricity

To understand electricity we need to understand the concept of electric charge first. Let us understand this concept using this example.
When two dry substances of different types are rubbed together and are then separated , each substances acquires property of attracting light pieces of paper , dry leaves, straw etc. The substances being rubbed acquire something which give them this property. That something is called **Fractional Electricity.** The substances are said to have become charged after acquiring or loosing electric charge.
The fractional electricity produced have been found to be of two types i.e., positive electricity (charge) and negative electricity (charge). The to substances rubbed together acquire equal and opposite charges.

Positive charge	**Negative charge**
Glass rod	Silk Cloth
Woolen cloth or cat skin	Amber, ebonite, rubber rod
Woolen carpet	Rubber shoe soles
Woolen coat	Plastic seat

2. Electric Charges

- Electric charge is a fundamental property like mass; length etc. associated with elementary particles for example electron, proton and many more.
- Electric charge is the property responsible for electric forces which acts between nucleus and electron to bind the atom together.

- Charges are of two kinds
    1. negative charge
    2. positive charge
- Electrons are negatively charged particles and protons, of which nucleus is made of, are positively charged particles. Actually nucleus is made of protons and neutrons but neutrons are uncharged particles.
- Electric force between two electrons is same as electric force between two protons kept at same distance apart i.e., both set repel each other but electric force between an electron and proton placed at same distance apart is not repulsive but attractive in nature
- All free charges are integral multiples of a unit of charge e, where e = -1.602×10^{-19} C i. e., charge on an electron or proton.
- Thus charge q on a body is always denoted by
  q = ne
  where n = any integer positive or negative

Unit of electric Charge

- Charge on a system can be measured by comparing it with the charge on a standard body.
- SI unit of charge is Coulomb written as C.
- 1 Coulomb is the charge flowing through the wire in 1 second if the electric current in it is 1A.
- Charge on electron is -1.602×10^{-19} C and charge on proton is positive of this value.

3. Conductors and insulators

- There is a category of materials in which electric charges can flow easily while in other materials charges cannot flow easily.
- Substances through which electric charges can flow easily are called conductors. All metals like copper, aluminum etc. are good conductors of electricity.
- Substances through which electric charges cannot flow are called insulators.
- Few examples of insulating materials are glass, rubber, mica, plastic, dry wood etc.
- Presence or absence of free electrons in a material makes it a conductor or insulator.
- Conductors have free electrons which are loosely held by nuclei of their atoms whereas insulators do not have free electrons as in insulators electrons are strongly held by nuclei of their atoms.

4. Electric potential and potential difference

- Charges present in a conductor does not flow from one end to another on their own.
- Electric charges or electrons move in a conductor only if there is a difference of electric pressure, called potential difference, along the conductor.
- This difference of potential may be produced by a battery, consisting of one or more electric cells.

- Potential difference across the terminals of the cell is generated due to chemical reaction within the cell.
- When the cell is connected to a conducting circuit element, the potential difference sets the charges inside the conductor in motion and produces an electric current.
- In order to maintain the current in a given electric circuit, the cell has to expend its chemical energy stored in it.
- The potential difference between two points in an electric field is defined as the amount of work done in moving a unit positive charge from one point to another point. So,

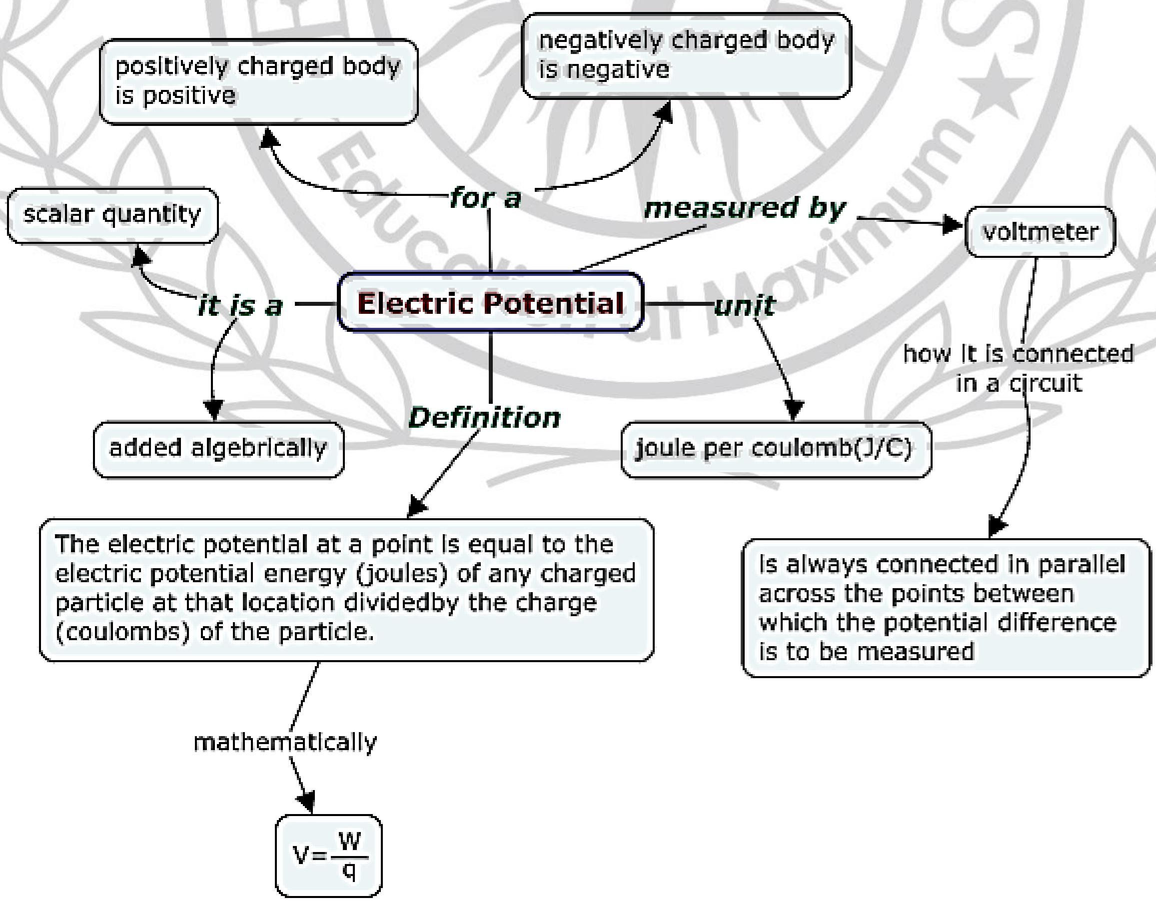
$$potential\ difference = \frac{work\ done}{quantity\ of\ charge\ transfered} = \frac{W}{Q} \qquad (1)$$

- The SI unit of electric potential difference is volt (V)
- The potential difference between two points is said to be one Volt if 1 Joule of work is done in moving 1 Coulomb of electric charge from one point to another. Thus

$$1\ Volt = \frac{1\ joule}{1\ Coulomb}$$

- The potential difference is measured by means of an instrument called the voltmeter.
- The voltmeter is always connected in parallel across the points between which the potential difference is to be measured.

Concept Map for electric Potential

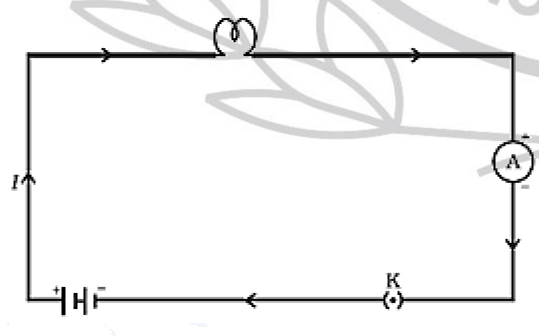


5. Electric current and electrical circuits

- Consider two metallic conducting balls charged at different potential are hanged using a non-conducting insulating wires .Since air is an insulator ,no charge transfer takes place
- Now if we join both the metallic wire using a conducting metallic wire then charge will flow from metallic ball at higher potential to the one at lower potential.
- This flow of charge will stop when the two balls would be at the same potentials.
- If somehow we could maintain the potential between the metallic balls through a cell or battery, we will get constant flow of the charge in metallic wire, connecting the two conducting balls
- This flow of charge in metallic wire due to the potential difference between two conductors used is called electric current.
- So, Electric current is expressed by the amount of charge flowing through a particular area in unit time.
- In other words, it is the rate of flow of electric charges (electrons) in a conductor (for example copper or metallic wire).
- If a net charge Q, flows across any cross-section of a conductor in time t, then the current I, through the cross-section is

  $$I = \frac{Q}{t} \qquad (2)$$

  The S.I. unit of electric current is Ampere (A)
- When 1 Coulomb of charge flows through a cross-section of conductor in 1 second then current flowing through the conductor is said to be 1 Ampere.
- Current is measured by an instrument called ammeter. It is always connected in series in a circuit through which the current is to be measured.
- A continuous and closed path of an electric current is called an electric circuit. For example figure given below shows a typical electric circuit comprising a cell, an electric bulb, an ammeter A and a plug key K.

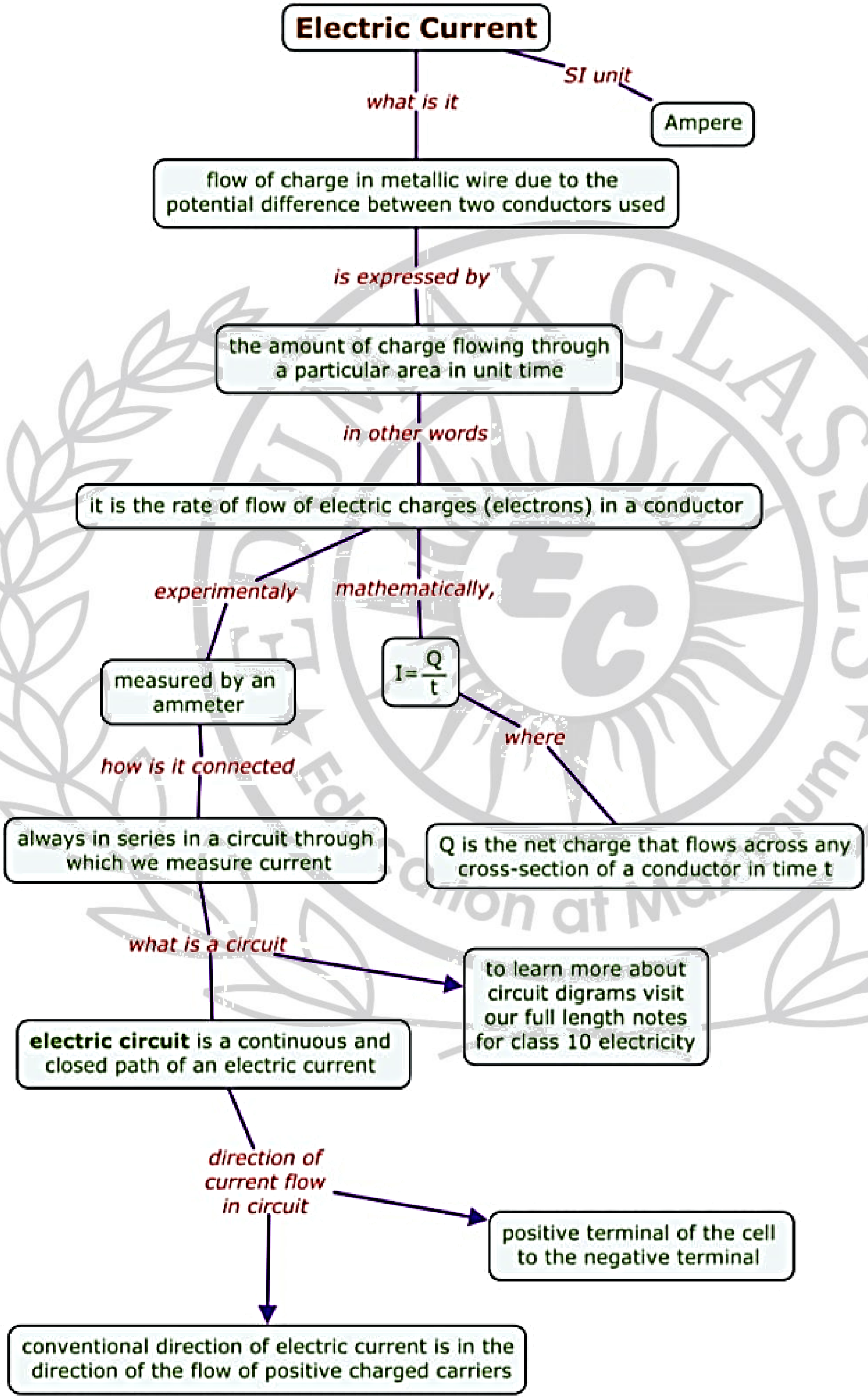


Note that the electric current flows in the circuit from the positive terminal of the cell to the negative terminal of the cell through the bulb and ammeter

- The conventional direction of electric current is from positive terminal of the cell to the negative terminal through the outer circuit.

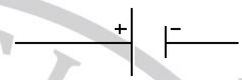
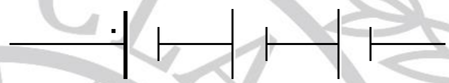
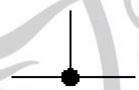
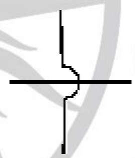
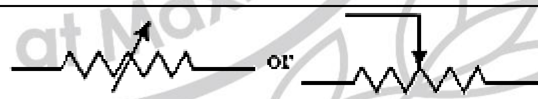
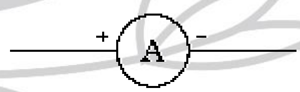
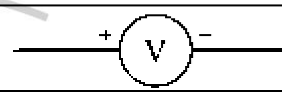
- Or we can say that conventional direction of electric current is in the direction of the flow of positive charged carriers.

Electric Current Concept Map



6. Circuit Diagrams

- We already know that electric circuit is a continuous path consisting of cell (or a battery), a plug key, electrical component(s), and connecting wires.
- Electric circuits can be represented conveniently through a circuit diagram.
- A diagram which indicates how different components in a circuit have to be connected by using symbols for different electric components is called a circuit diagram.
- Table given below shows symbols used to represent some of the most commonly used electrical components

S. No.	Component	Symbol
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	

Ohm's Law

- Ohm's law is the relation between the potential difference applied to the ends of the conductor and current flowing through the conductor. This law was expressed by George Simon Ohm in 1826.
- **Statement of Ohm's Law**
  If the physical state of the conductor (Temperature and mechanical strain etc.) remains unchanged, then current flowing through a conductor is always directly proportional to the potential difference across the two ends of the

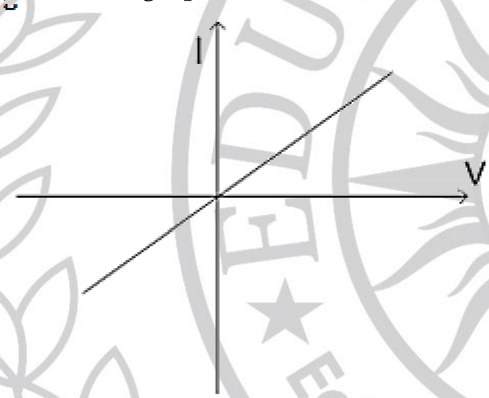
conductor
mathematically
$V \propto I$
or
$V=IR$
where constant of proportionality R is called the electric resistance or simply resistance of the conductor.

- Value of resistance depends upon the nature, dimension and physically dimensions of the conductor.
- From Ohm's Law

$$V = IR \qquad (3)$$
$$R = \frac{V}{I} \qquad (4)$$

Thus electric resistance is the ratio of potential difference across the two ends of conductor and amount of current flowing through the conductor.

- If a graph is drawn between the potential difference readings (V) and the corresponding current value (I), then the graph is found to be a straight line passing through the origin as shown below in the figure



IV relation for resistors obeying Ohm's Law

- From graph we see that these two quantities V and I are directly proportional to one another.
- Also from this graph we see that current (I) increases with the potential difference (V) but their ratio V/I remain constant and this constant quantity as we have defined earlier is called the Resistance of the conductor.
- Electric resistance of a conductor is the obstruction offered by the conductor to the flow of the current through it.
- SI unit of resistance is Ohm (Ω) where 1 Ohm=1 volt/1 Ampere or $1\Omega=1VA^{-1}$. Bigger units of resistance are Kilo-Ohm and Mega-Ohm
- The resistance of the conductor depends
    1. on its length,
    2. on its area of cross-section
    3. on the nature of its material

- Resistance of a uniform metallic conductor is directly proportional to its length (l) and inversely proportional to the area of cross-section (A). That is,

  $R \propto l \; and \; R \propto \frac{1}{A}$

  Or,

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

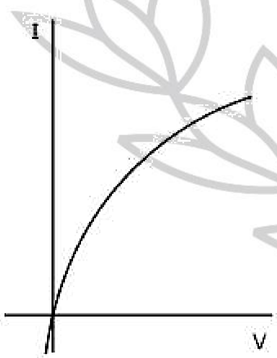
  Or,

  $$R = \rho \frac{l}{A} \qquad (5)$$

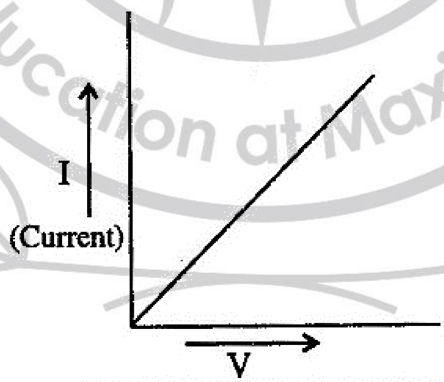
  Where ρ is the constant of proportionality and is called the electrical resistivity of the material of the conductor.

- The SI unit of resistivity is Ω m. It is a characteristic property of the material.
- The metals and alloys have very low resistivity in the range of 10^{-8} Ω m to 10^{-6} Ω m. They are good conductors of electricity.
- Insulators like rubber and glass have resistivity of the order of 10^{12} to 10^{17} Ω m.
- Both the resistance and resistivity of a material vary with temperature.

Ohmic and Non-Ohmic resistors (or devices)
From above figure 2 we can see that straight line graph means that ratio V/I is constant . This constant ratio is called resistance R of the conductor. Resistance may be ohmic or non-ohmic.
(a) Resistors (or devices) for which potential difference and current graph is a straight line are called ohmic resistors. Their resistance remains same throughout their operation.
Examples are metallic conductors.
(b) Resistors (or devices) for which potential difference-current graph is not a straight line are called non-ohmic resistors.



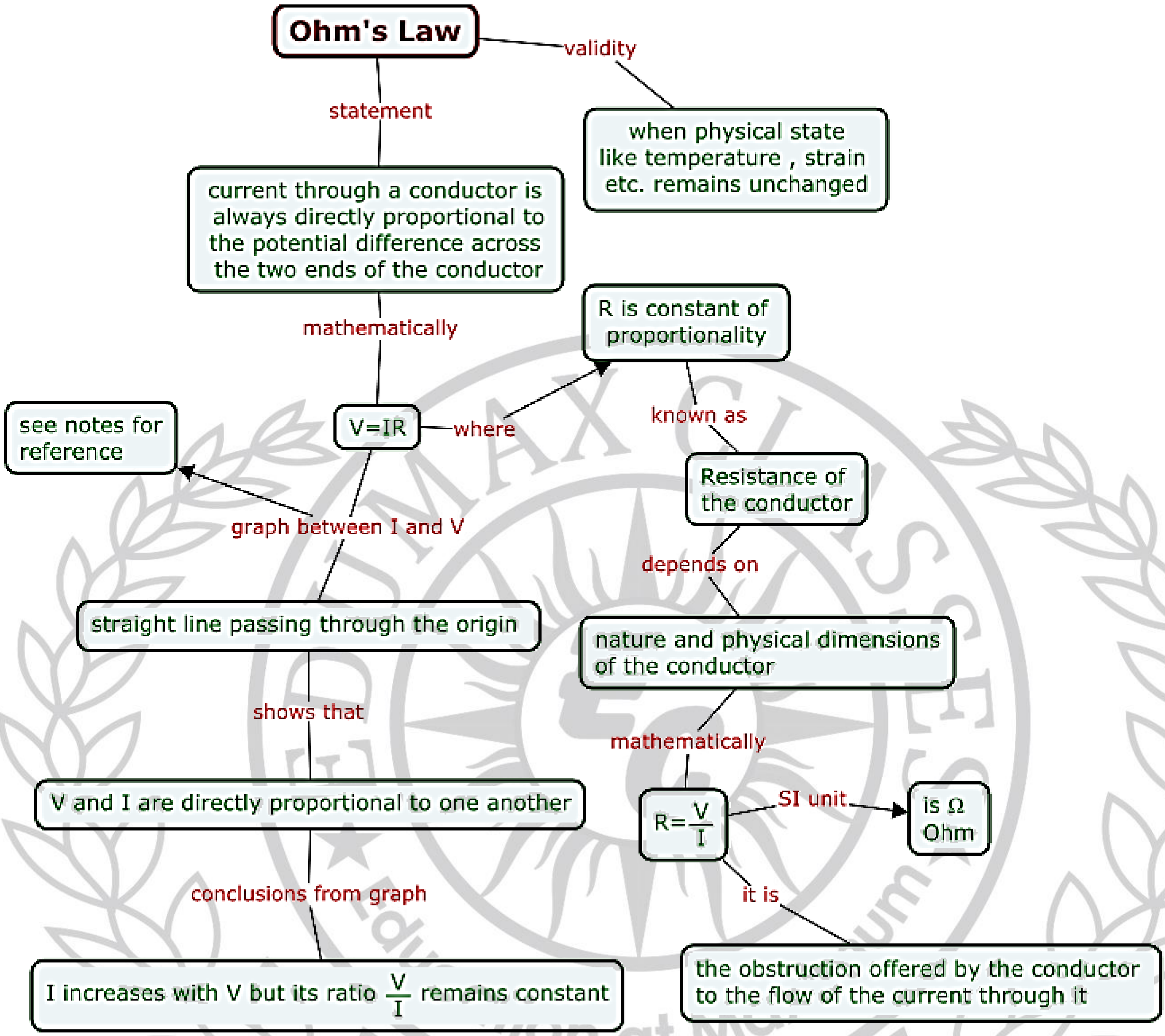
Voltage Non-Ohmic device



Voltage (Ohmic Conductor)

Examples are liquid electrolytes, diodes etc.

Concept Map of Ohm's Law



Question: What causes resistance in a conductor?

Answer. When electrons move from one end of the conductor to the other end , then because of the potential difference they collide with the electrons, atoms and ions present in the conductor. Due to these collisions movement of the electrons gets restricted through the conductor. Thus "resistance is the property of the conductor due to which it opposes the flow of charge".

8. Factors affecting of resistances of a conductor

Electric resistance of a conductor (or a wire) depends on the following factors

1. **Length of the conductor: -**
   From equation 5 we can see that resistance of a conductor is directly proportional to its length. So, *when length of the wire is doubled, its resistance also gets doubled; and if length of the wire is halved its resistance also gets halved.*
   Thus a long wire has more resistance then a short wire.

2. **Area of cross-section:-**
   Again form equation 5 we see that resistance of a conductor is inversely proportional to its area of cross-section. So, *when the area of cross-section of a wire is doubled, its resistance gets halved; and if the area of cross-section of wire is halved then its resistance will get doubled.*
   Thus a thick wire has less resistance and a thin wire has more resistance.

3. **3. Nature of material of conductor:-**
   Electrical resistance of a conductor also depends on the nature of the material of which it is made. For example a copper wire has less resistance then a nichrome wire of same length and area of cross-section.

4. **4. Effect of temperature:-**
   It has been found that *the resistance of all pure metals increases on raising the temperature and decreases on lowering the temperature.*
   Resistance of alloys like manganin, nichrome and constantan remains unaffected by temperature.

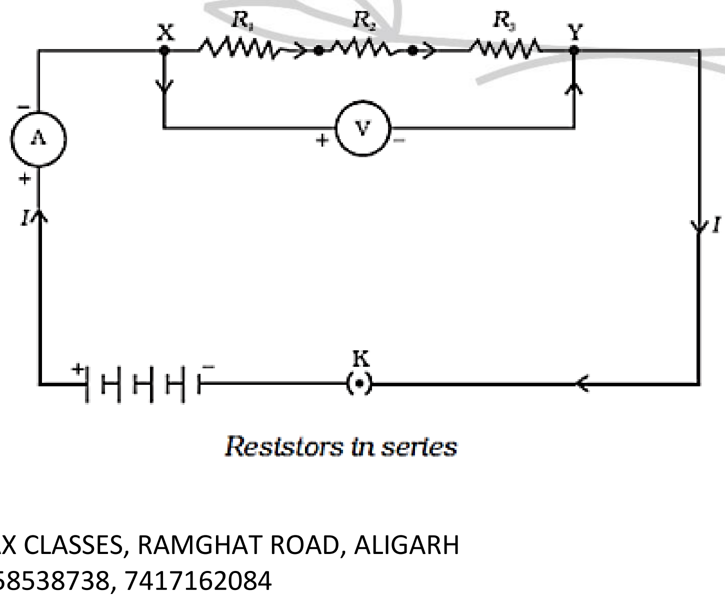
9. Resistance of a system of resistors

- We know that current through a conductor depends upon its resistance and potential difference across its ends.
- In various electrical instruments resistors are often used in various combinations and Ohm's Law can be applied to combination of resistors to find the equivalent resistance of the combination.
- The resistances can be combined in two ways
  1. In series
  2. In parallel

To increase the resistance individual resistances are connected in series combination and to decrease the resistance individual resistances are connected in parallel combination.

9(a) Resistors in Series

- When two or more resistances are connected end to end then they are said to be connected in series combination.
- Figure below shows a circuit diagram where two resistors are connected in series combination.

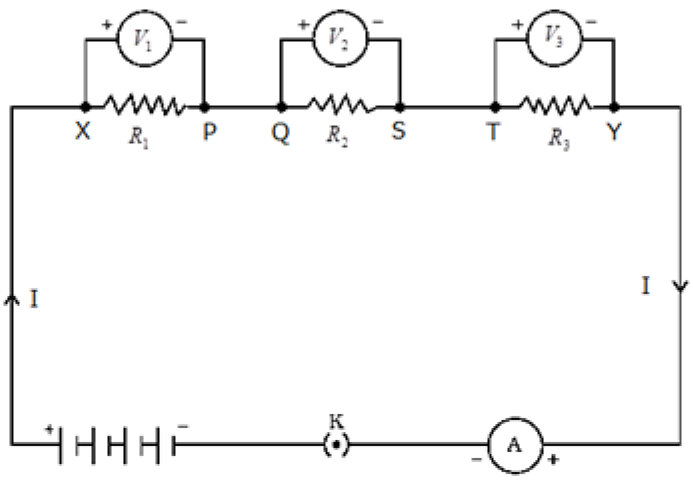


Resistors in series

- Now value of current in the ammeter is the same irrespective of its position in the circuit. So we conclude that " *For a series combination of resistors the current is same in every part of the circuit or same current flows through each resistor* "

- Again if we connect three voltmeters one across each resistor as shown below in the figure 4.The potential difference measured by voltmeter across each one of resistors R_1 , R_2 and R_3 is V_1 , V_2 and V_3 respectively and if we add all these potential differences then we get

$$V = V_1 + V_2 + V_3 \qquad (6)$$



This total potential difference V in equation 6 is measured to be equal to potential difference measured across points X and Y that is across all the three resistors in figure 3. So, we conclude that <"*the total potential difference across a combination of resistors in series is equal to the sum of potential differences across the individual resistors.*"

- Again consider figure 4 where I is the current flowing through the circuit which is also the current through each resistor. If we replace three resistors joined in series by an equivalent single resistor of resistance R such that, the potential difference V across it, and the current I through the circuit remains same.

- Now applying Ohm's law to entire circuit we get<

$$V = IR \qquad (7)$$

On applying Ohm's law to the three resistors separately we have,<

$$V_1 = IR_1 \qquad (7.1)$$
$$V_2 = IR_2 \qquad (7.2)$$
$$V_3 = IR_3 \qquad (7.3)$$

From equation 6

$$IR = IR_1 + IR_2 + IR_3 \qquad (8)$$

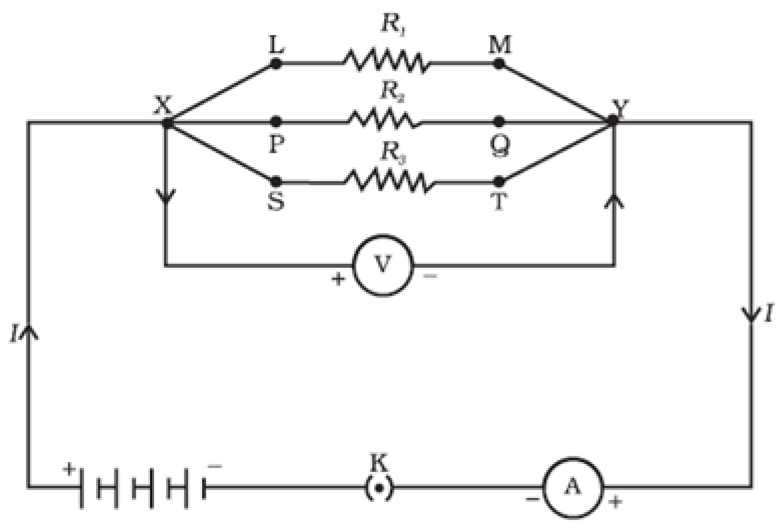
Or,

$$R = R_1 + R_2 + R_3 \qquad (9)$$

So here from above equation 9 we conclude that when several resistances are connected in series combination, the equivalent resistance equals the sum of their individual resistances and is thus greater than any individual resistance.

9(b) Resistors in parallel

- When two or more resistances are connected between the same two points they are said to be connected in parallel combination.
- Figure below shows a circuit diagram where two resistors are connected in parallel combination.



IMPORTANT NOTE

1. When a number of resistors are connected in parallel, then the potential difference across each resistance is equal to the voltage of the battery applied.
2. When a number of resistances are connected in parallel, then the sum of the currents flowing through all the resistances is equal to total current flowing in the circuit.
3. When numbers of resistances are connected in parallel then their combined resistance is less than the smallest individual resistance. This happens because the same current gets additional paths to flow resulting decrease in overall resistance of the circuit

- To calculate the equivalent resistance of the circuit shown in figure 5 consider a battery B which is connected across parallel combination of resistors so as to maintain potential difference V across each resistor. Then total current in the circuit would be

$$I = I_1 + I_2 + I_3 \qquad (10)$$

Since potential difference across each resistors is V. Therefore, on applying Ohm's Law

$$V = I_1R_1 = I_2R_2 = I_3R_3$$

Or,

$$I_1 = \frac{V}{R_1}, I_2 = \frac{V}{R_2}, I_3 = \frac{V}{R_3}$$

Putting these values of current in equation 10 we have

$$I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

If R is the equivalent resistance of parallel combination of three resistors heaving resistances R_1, R_2 and R_3 then from Ohm's Law

$$V = IR_{eq}$$

Or,

$$I = \frac{V}{R_{eq}} \qquad (11)$$

Comparing equation (10) and (11) we get

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

- For resistors connected in parallel combination reciprocal of equivalent resistance is equal to the sum of reciprocal of individual resistances.
- Value of equivalent resistances for capacitors connected in parallel combination is always less than the value of the smallest resistance in circuit.

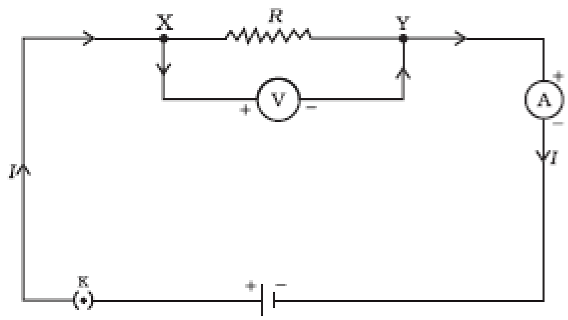
10. Heating Effect of Electric current

- When electric current passes through a high resistance wire, the wire becomes and produces heat. This is called heating effect of current.
- This phenomenon occurs because electrical energy is gets transformed into heat energy when current flows through a wire of some resistance say R Ω.
- Role of resistance in electrical circuits is similar to the role of friction in mechanics.
- To we will now derive the expression of heat produced when electric current flows through a wire.

To we will now derive the expression of heat produced when electric current flows through a wire.

- For this consider a current I flowing through a resistor of resistance R. Let V be the potential difference across it as shown in the figure 6
- Let t be the time during which charge Q flows. Now when charge Q moves against the potential difference V , then the amount of work is given by

$$W = Q \times V \qquad (12)$$



Therefore the source must supply energy equal to VQ in time t. Hence power input to the circuit by the source is

$$P = V\frac{Q}{t} = VI \qquad (13)$$

- The energy supplied to the circuit by the source in time t is P×t that is, *VIt*. This is the amount of energy dissipated in the resistor as heat energy.
- Thus for a steady current I flowing in the circuit for time t , the heat produced is given by

  $$H = VIt \qquad (14)$$

  Applying Ohm's law to above equation we get

  $$H = I^2Rt \qquad (15)$$

  This is known as Joule's Law of heating
- According to Joule's Law of Heating , Heat produced in a resistor is
  (a) Directly proportional to the square of current for a given resistor.
  (b) Directly proportional to resistance of a given resistor.
  (c) Directly proportional to time for which current flows through the resistor.

11. Applications of heating effect of current

1. The heating effect of current is utilized in the electrical heating appliances for example electric iron, room heaters, water heaters etc.
2. The heating effect of electric current is utilized in electric bulbs or electric lamps for producing light.
3. An electric fuse is an important application of the heating effect of current. The working principle of a fuse wire is based on the heating effect of current. When high current flow through the fuse (current higher than the rated value) then the heat developed in the wire melts it and breaks the circuit.
4. In an electric heater one type of coil is used. A high resistance material like nichrome or same type of material is used as coil. The coil is wound in grooves on ceramic format or china clay. Flowing electric current through the coil it becomes heated. Due to high resistance the coil becomes red color forms.

12. Electric Power

- Rate of doing work or the rate of consumption of energy is known as **POWER**
  Mathematically,

$$Power = \frac{Work\ done}{time\ taken} = \frac{W}{t} \qquad (16)$$

- SI unit of power is Watt which is denoted by letter W. The power of 1 Watt is a rate of working of 1 Joule per second. Actually Watt is a small unit, therefore , a bigger unit of electric power called Kilowatt is used for commercial purposes. Also ,
  1 kilowatt = 1000 Watts
  So," the rate at which electric work is done or the rate at which electric energy is consumed is called electric power "

- We will now derive formula for the calculation of electric power.
  From equation 14 we know that

$$Power = \frac{Work\ done}{time\ taken} = \frac{W}{t}$$

  Now we know that work done W by current I when it flows for time t under a potential difference V is given by

$$W = V \times I \times t \ \ Joules$$

  Putting this value of work done in equation 16 we get

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

  Or,

$$P = VI \qquad (17)$$

  Hence,
  Electric Power = voltage x current

12 (a) Power in terms of *I* and *R*

- From equation 17 we know that
  P=VI
  Now from Ohm's law

$$V = IR$$

  Putting above equation in equation 15 we get
  P=I×R×I
  Power , $P=I^2 \times R$

  Above formula is used to calculate power when only current and resistance are known to us.

12 (b) Power in terms of *V* and *R*

- From equation 17 we know that P=VI Now from Ohm's law

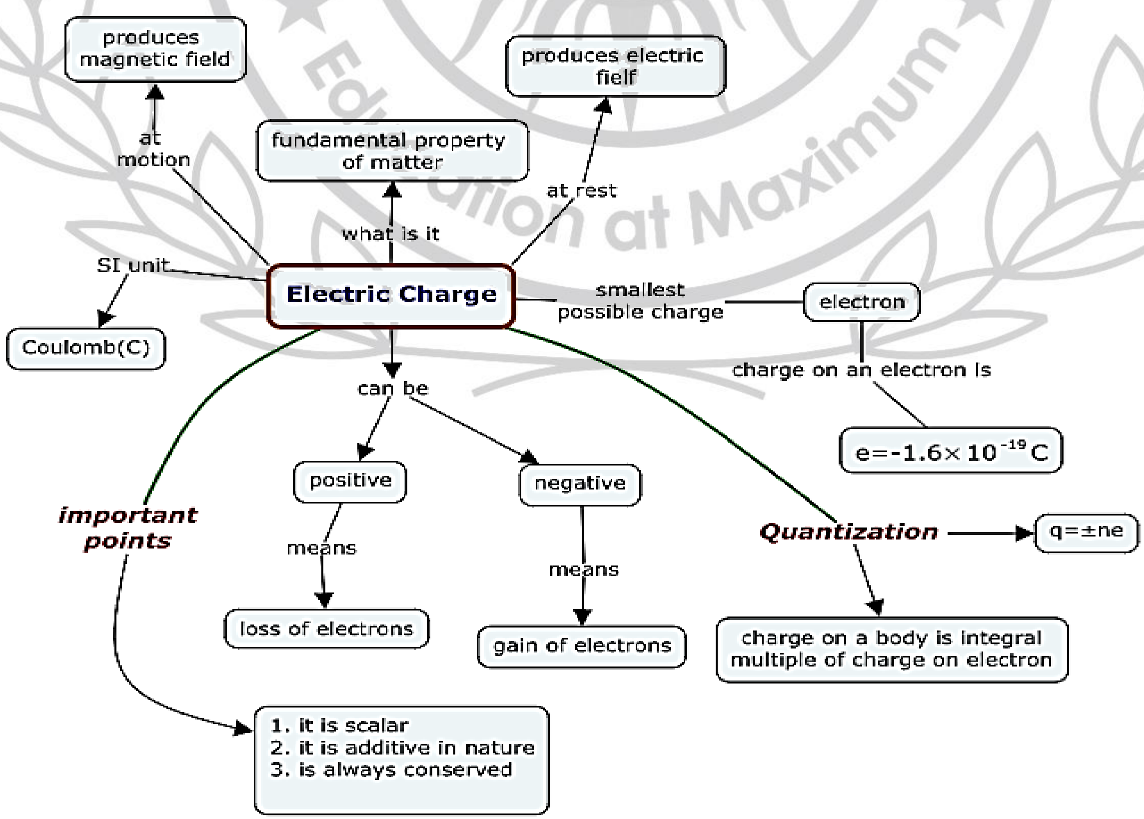
$$V = IR$$

Or we have

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

- Putting this value of I in equation 15 we get
  P=V×V/R
  $P=V^2/R$
  This formula is used for calculating power when voltage *V* and resistance *R* is known to us.
- It is clear from the above equation that power is inversely proportional to the the resistance.
- ***Thus the resistance of high power devices is smaller then the low power ones.*** For example , the resistance of a 100 Watt bulb (220 V) is smaller then that of 60 Watt (220 V) bulb.
- We have three formulas for calculating electric power. These are
  (1) P=V×I
  (2) P= Power , $P=I^2R$
  (3)P=V2RP=V2R
  You must memorize these formulas as they would be used to solve numerical problems.
- When electrical appliance consumes electrical energy at the rate of 1 Joule per second , its power is said to be 1 Watt.
- Rate at which electric work is done or the rate at which electric energy is consumed , is called electrical power.

Concept Map for Electric Charge



Concept Map for Materials (conductors, insulators & superconductors)