Electric Charge

An electric charge is one of the fundamental properties of matter that determines its electric and magnetic properties

- The smallest and the most elementary charge is the charge of 1 electron
- The SI unit of charge is coulomb
- An electron has a charge of 1.6×10^{-19} coulomb (C).
- No object can have a charge less than the charge of 1 electron.
- Thus, a charge of 0 5 x 10^{-19}C or 1.6 10^{-20}C is not possible.
- The charge on a body will always be a multiple of the charge of an electron.

Hence, the charge of an electron s also called the fundamental charge.

Exercise I

Q.1 Electric charge determines the ________ and ___________ properties of a matter

Q.2 S.I. unit of charge is ______

Q.3 An electron has a charge of __________ C.

0.4 The charge on a body always exists as a ____________ of the charge of an electron.

Q.5 Fundamental charge is the charge of_____________.

Electric Current

An ordered motion of charged particles in a definite direction is termed as electric current Its magnitude is determined by the amount of net charge flowing through a cross section, perpendicular to the direction of the flow in unit time.

If we observe that 20 C of net charge flows across a cross section of a current carrying wire in 4 seconds, we calculate the current as:

20C/4s = 5C/s

The SI. unit of electric current is ampere (A)

Ampere is a fundamental unit and Coulomb is derived from ampere. So 1C/s=1A

Hence, in the above case, the current is 5 A.

From the definition of electric current, the formula for calculating electric current can be derived as

$I = Q/t$

Where I stand for current, Q for charge and 't' for time taken

Exercise II

Q.1 Which quantity determines the magnitude of electric current?

Q.2 SI unit of electric current is _______

Q.3 10 C of net charge flows across a cross section of a current carrying wire in 5 seconds What will be the magnitude of the current through the wire?

Q4 Which of the following is a fundamental unit?

(a) Coulomb (b) Ampere

Q.5 4 A of current passes through a wire in 0.5 seconds. Calculate the amount of charge flowing through the wire

Potential

Consider a 1 kg mass lying on the ground floor. It is not capable of doing any work. But if it is taken to the first floor it now has the capability to do work. It has gained the ability to do work because of its position. Hence it has some potential to do work. This capability comes from the fact that we have done some work on the mass against the force of gravity which gets stored in it in the form

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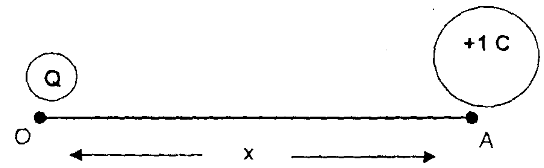
of energy. Also, we know that anybody possessing energy has the ability to do some work.

So, by this, we understand that the ability (potential) of 1 kg mass to do any work is zero at the ground level and it increases with the increase in the height.

Electric potential is also similar. Let us assume a large positive charge Q kept at point 0 as shown below:

Now Q can influence other charges that come in its vicinity.
Let us hold a ball of charge +1 C near the charge Q at point A, x units from 0.

Electric potential is a scalar quantity and it refers to the potential energy per unit charge associated with a position under the influence of a charged body. Its S I unit is volt. Suppose a charge of 3C is placed at a point A having 10 V potential, then the charge is capable of doing 30 J of work. Thus, we can define the work done by a charge in moving from one point to another in an electric field, as the product of charge and potential at that point



W=VQ

We know that C It'. So, the above equation can also be written as

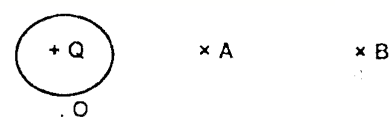
W= VIt

Potential Difference

Let us consider the charged body due to which an electric field of influence is created in the surroundings

We have two positions A and B in the vicinity of the charged body kept at point 0. If we place +1 C charge first at A and then at B, in which case do you think the capability to do work will be the maximum?

The capability will be greater when the charge is placed at point A because the force of repulsion is greater at point A, Now if we allow the charge kept at A to move freely. it will move towards B which is at a lower potential?



Where do you think will the charge stop?

Hence, we can conclude that:

A charge, free to move will always move from a higher potential to a lower potential.

Exercise III

Q.1 Potential is a _______ quantity.

Q.2 What is the SI unit of electric potential?

Q.3 The potential at a point A is 5 V and a charged body of 2 C is kept at that place. What does it mean?

Q.4 A charge, free to move will always move from a _______ potential to a _______ potential.

Q.5 Calculate the work done in moving a charge of 5 C through a 10 V battery

Q.6 30 J of work is done on a charge while it moves through a region of 1 5V potential difference. Calculate the magnitude of the charge.

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Q.7 50 mA of current is generated through a circuit switched on for 5 minutes. If the potential difference within the circuit is 6 V, calculate the work done in moving the charge

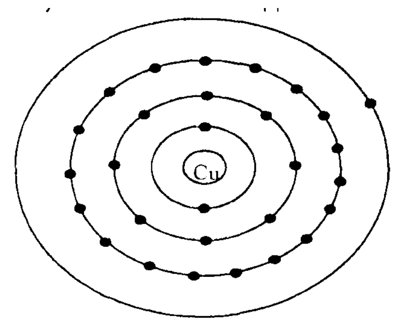
Q.8 30 J of work is done in moving a charge through an electric circuit having a 10 V battery If 5 A of current is passing through the circuit, calculate the duration for which current will flow.

Electrons As Charge Carriers

Metals are good conductors of electricity because they have a sea of valence electrons. If we study the electronic configuration of a copper atom.

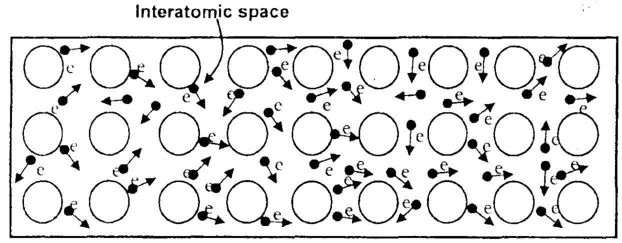
Electronic configuration of Cu atom is 2, 8, 18, 1

From the structure of copper atom, it is clear that there is one electron in its outer most shell. This valence electron is loosely bound to the nucleus. This electron becomes free to move around in the intra-atomic spaces when it gains some energy. In the interatomic space, there is a sea of free electrons which move randomly. The situation is similar to a room full of people where everybody is trying to move in a different direction. Similarly, there is only a chaos but no net movement of electrons.

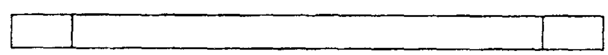


The motion of electrons is due to the internal energy of the material which is increased by the temperature of the body. The more the energy, the more will be its temperature and vice—versa.

So, in a metallic wire, we have a chaotic situation where net movements do not happen because the electrons are not oriented in a single direction; rather they are moving in different directions. To get them moving, we have to assign them a definite direction.



To give a direction to the randomly moving electrons, we need to apply a potential difference across the conductor

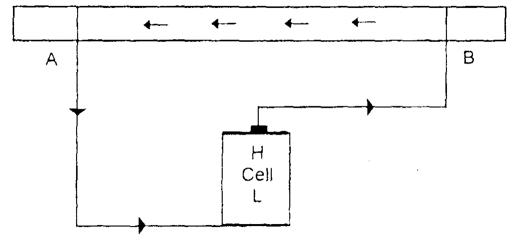


Applying a potential difference across points A and B on the conductor means we are keeping point A at potential V1 and point B at potential V2. For example, we keep point A at 10 V and point B at 12 V The potential difference across two points will be 2 V. We know that charged particles move from a higher potential to a lower potential. So, all the current start flowing from point B to point A.

Now, a question arises as to what happens to the charge carriers that reach point A? If we need a continuous flow of charge carriers through the wire, point B should be able to supply unlimited number of charge carriers, and this again seems to be an impossible situation.

The solution is provided by a simple device called a cell which serves as a charge pump. A cell not only provides the potential difference but also recycles the charge carriers. Let us see how.

The ends of the cell are at different potentials. The end that has a higher potential (H) is connected to B and the end that has a lower potential (L) is connected to A. As the charge carriers reach A, they are directed towards the low potential terminal of the cell. Once they reach the low potential terminal after dissipating energy. Chemical energy of the cell pumps them up to the terminal at the higher potential from which they reach B and the cycle continues.



Exercise III

Q.1 Which energy is responsible for the motion of electrons inside a conductor?

Q.2 What should be done to give a particular direction to the randomly moving electrons inside a conductor?

Q.3 Which of the following statements is true, when an external source of electrical energy is provided with, in a circuit?

(i) Charged particles move from lower to higher potential

(ii) Charged particles move from a higher to a lower potential.

Q,4 What should we do to maintain a continuous flow of electrons from one end to the other end of a conductor?

Q.5 In metals, conduction happens through the ______

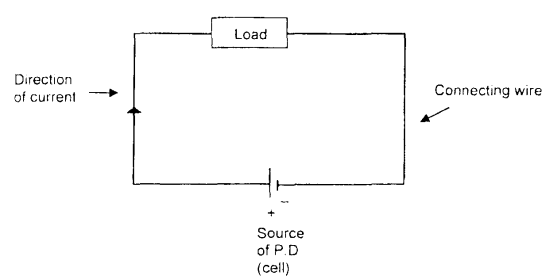
Circuit:

When there is a flow of charge through a continuous path, the path is called a circuit

The main components of a circuit are:

(A) A Source Of Potential Difference: Devices such as cells, generators, etc. act as sources of potential difference. A source can increase potential difference if connected in a right manner.

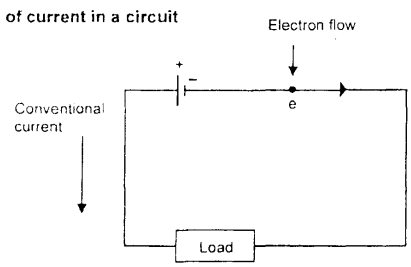
(B) Load : A load is a device that consumes electrical energy and liberates other forms of useful energy. Bulbs, heaters, toaster etc. are all loads. A load usually decreases the potential.



(C) Connecting Wires : To maintain continuity in a circuit we need to connect the different components together through a path of zero resistance This path is provided by the connecting wires

In a circuit, the direction of the flow of current is taken to be from the positive terminal towards the negative terminal. This is called the direction of conventional current but the actual flow of electrons is from the negative terminal to the positive terminal.

Direction of current in a circuit



Resistance In A Wire: As we have discussed earlier, the free electrons are in random motion within a metallic wire The electrons collide with the kernels in the crystal and increase the internal energy of the wire, thus, increasing the temperature.

Resistance is that property which limits the amount of current that flows through a metallic conductor Mathematically, t is defined as the ratio of potential difference applied across a conductor and the current through the conductor.

$$\text{Resistance (R)} = \frac{\text{potential difference applied (V)}}{\text{current due to movement of electrons (I)}}$$

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

Exercise IV

Q.1 What is an electric circuit?

Q.2 Categorize the following as sources and loads:
Cell, bulb, heater, generator, television

Q.3 A load usually _______ the potential difference

Q.4 What is the need of connecting wire within a circuit?

Q.5 Conventional current always flows from ______ terminal to _______ terminal of a cell.

Q.6 Direction of flow of electric current is ______ to direction of the flow of conventional current

Q.7 Resistance is the property of a material which opposes the flow of _______ through a conductor

Q.8 Match the following.

Physical quantity	Units
(a) Charge	(i) A
(b) Current	(ii) V
(C) Resistance	(iii) C
(d) Potential	(iv) 0

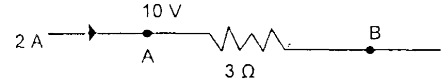
Resistors

Resistors are two terminal devices which provide resistance to the flow of current. A resistor typically decreases the potential in a circuit. The decrease in potential (potential drop) is calculated as the product of the current flowing through the resistor and its resistance.

$|\Delta V| = IR$

The SI unit of resistance is ohm (Ω). One ohm is defined as the resistance of a conductor across which a potential difference of one volt generates 1 ampere of electric current.

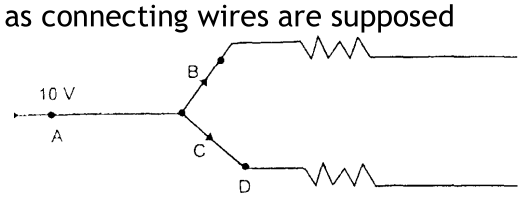
Let the potential at one end (A) of the resistor, as shown in the following diagram, be 10 V.



The potential drop across the resistor = 2A x 3 Ω = 6 V

Hence, the potential at B = 10 V –6 V = 4 V

Potential drop across a connecting wire is zero as connecting wires are supposed to have a negligible resistance. All the points A, B, C and D are at the same potential.



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Specific Resistance or Resistivity: When the potential is applied at the end points of a conductor, the resistance of that conductor is directly proportional to the length of the conductor.

R α l (i)

it has been observed that resistance is inversely proportional to the area of cross section of the conductor

R α 1/a (ii)

By combining (i) and (ii), we get

R α l/a

R= ρ l/a

Here ρ is the constant of proportionality and is called the electrical resistivity of the material of the conductor. It is the characteristic property of the material.

SI Unit Of Specific Resistance

We know that R = ρ l/a

Or ρ= R a/l or ρ= ohm X m^2/m or ρ= ohm m

The specific resistance is measured in Ωm. Electrical resistivity is the measure of the strength of a material's opposition to the flow of electric current. A low resistivity indicates that the material readily allows the movement of electric charge. The metals and alloys have very low resistivity having range 10^{-8} Ωm to 10^{-6} Ωm Cm, Electric resistivity of metals increases with temperature. Also, at a high temperature, the resistance of a metal increases linearly with the temperature.

Exercise VI

Q.1 Resistance of a metallic wire of length 2 m is 50 Ω and the diameter of the wire is 1 mm Calculate the resistivity of the material.

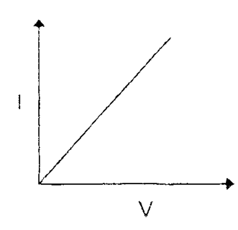
0.2 How does the resistance of a metallic wire get affected when its area of cross section becomes double. without changing the original length?

Q.3 The resistance of a wire of uniform diameter d' and length l's 'R'. Calculate the resistance of another wire of the same material with diameter 2 d and length 4l

0.4 The resistance of a 20 cm long wire is 50 ohm. The wire is stretched to a uniform wire of 40 cm length Calculate the new resistance in ohm.

Ohm's Law: This law states that in an electric circuit, the current flowing through the conductor is directly proportional to the potential difference across its two ends

V α I



Here. I is the current and V is the potential difference

The graph of the current and voltage of an ohmic conductor is a straight line through the origin Slope of the graph s given by Δ I/Δ V which indicates 1/R. Resistance (R) of a conductor is a material property

Note that ohm's law applies (i.e resistance is constant) only when the physical conditions remain constant These conditions are.

- temperature
- strong magnetic field strain
- light

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