Electricity, Magnetism and Semiconductors

CONCEPT OF CHARGE

Let us consider a simple experiment. A glass rod and prece of silk cloth is taken. In a small tray smaller pieces of thin paper are kept

Silk cloth is wrapped around the glass rod and the glass rod in vigorously moved in and our off that silk cloth for some time and held over the tray containing paper pieces

I will be observed that paper pieces are attracted towards the glass tod. What is the reason for this?

In a similar manner when hair on the head are combed by moving a plastic comb through them number of times. The comb is held over the tray containing the paper pinces. In this case also, it is observed that paper pieces are attracted towards the comb

This attraction of the paper pieces is on account of electric charge developed on the glass rod a well as on the plastic comb

When glass rod is moved in and out of silk cloth or plastic comb is moved through the hair there is friction between them.

The electric charge is developed on glass rod and the plastic comb on account of friction between two bodies as such the electric charge so produced is called frictional electricity. The charges so produced are stationery hence the electricity is generally called static electricity.

Every matter is composed of atoms. The atoms consist of protons, neutrons and electrons. The protons carry positive charge, electrons carry negative charge and the neutrons do not carry any charge.

The positive charge of protons is equal to the negative charge of the electrons as such atom as a whole is electrically neutral.

When two bodies are rubbed together, the electrons from atoms on the surface of one body are transferred to the other body.

The body from which the electrons are transferred is now short of electrons as such it becomes positively charged and the body to which electrons are transferred, has excess of electrons and becomes

negatively charged. The quantum of electric charge developed, depends upon the number of electrons transferred

In the above illustrations, when a glass rod is rubbed with silk cloth, electrons from the surface of glass rod are transferred to the silk cloth with the result the glass becomes positively charged and silk rod becomes negatively charged.

Similar to experiment with glass rod, if an ebonite rod is rubbed against a piece of wool and held over the tray containing small pieces of paper, the paper pieces are attracted towards the ebonite rod. This shows that ebonite rod is also electrically charged on account of friction between it and wool.
It must be noted from these examples that electrons are neither created nor destroyed. They are simply transferred from one object in the system to the other object in the same system. The total electric charge in an isolated system always remains constant. This is known as principle of conversation of charges

2.2 FORCES BETWEEN ELECTRIC CHARGES

Two glass rods are rubbed with silk cloth and then suspended from some support and brought nearer.
It is observed that both the glass rods try to move away from each other i.e. repel from each other.
Now an ebonite rod rubbed with wool is suspended from a support and brought nearer to the suspended glass rod, it is observed that both the rods try to move closer i.e. attract each other.
In earlier experiments we have noted that the electric charge developed on glass rod is positive and that developed on the ebonite rod is negative, as such we can summarize the above observations as "like charges repel and unlike charges attract each other".
The unit for electric charges is named as Coulomb and denoted by symbol (C).
The charge on an electron is equal to 1.6 x 109 coulomb

COULOMB'S INVERSE SQUARE LAW

charges is given by a law known as Coulomb's inverse square law.
The law states that the force between two electric charges is directly proportional to their strengths and inversely proportional to the square of the distance between them and acts along the line joining them

Consider two electric charges of strengths Q, and Q placed distance d apart. Let F be the force between them. Then according to the Coulomb's Law

permittivity of the medium. Its value depends upon the medium in which the charges are placed.
It is found that,
EK where
Permittivity of free space i.e.
vacuum
K. Relative permittivity or di-electric constant of the
medium
The value of di-electric constant K is equal to 1 for aim and vacuum. The permittivity of the free space is a fixed constant. Its value is equal 8.85x10 farad/m.
The expression for the force between two electric charges can be written as

$E = 1/(4pi * 8.85 * 10^{-11}) * (Q_{1}*Q_{2})/(K * d^{2}) = 8.897 * 10^{9} * (Q_{1}*Q_{2})/(K * d^{2})$
As 8.897 is almost equal to 9 the equation is written as $F = 9 * 10^{9} * (Q_{1}*Q_{3})/(K * d^{2})$

2.4 UNIT CHARGE: COULOMB
Let Q, Q, and the charges be like and having magnitude I coulomb, and let them be placed in air (or in free space) ie. K = 1 distance I m apart. Then we get F 9x 10x1x1 1x1 = 9x 10" Newton
This enables us to define charge of 1 coulomb. The charge which when placed in air or free space from a like charge repels it with a force of 9 x 10 newton is called charge of one coulomb. The natural unit of charge is the charge possessed by an electron. It is equal to 1.6029 x 10 coulomb.
Electric current is constituted when electric charge flows through a conductor. The electric charge flowing per unit time is called electric current. Le. Electric current = Electric charge time 19 Q=It When 1 1 ampere, 1 = 1 second, Q1x1=1 coulomb
Hence we can say that when a current of one ampere flows for 1 second through a conductor, the electric charge conducted through the conductor is equal to one
coulomb
Coulomb is a very large unit hence a smaller unit known as micro-coulomb µC is used.
1 µC 10 coulomb

ELECTRIC FIELD

The space surrounding an electric charge where its effects such as attraction or repulsion are observed is called electric field.
Theoretically electric field of an electric charge extends up to infinity. However the effect is more pronounced near the charges and as the distance from the charge increases its intensity goes on decreasing.

INTENSITY OF ELECTRIC FIELD

The intensity of electric field at a point is defined as the force acting on unit positive charge imagined to be placed at that point.
Let F be the force acting on a charge of Q coulomb placed at a point in electric field of the charge then intensity of electric field at that point, say E, is given by the relation
Intensity of Electric Field
Force Charge
F
The unit of electric field intensity is newton/coulomb E= 1QQ Aπε, Kα 1 AC
Fig. 2.6.1
Consider a unit charge imagined to be placed at a point B situated at a distance d from a charge of Q coulomb placed at point A.
The force acting on the unit charge placed at point B. due to charge Q at point A is intensity of electric field at point B due to charge Q kept at point A. Thus we can write
Intensity of electric field at point = 9x10° Kd

ELECTRIC POTENTIAL

It is observed that the liquids flow from higher level to lower level. The flow continues till the leveh are equalized
Heat flows from a body at higher temperature to a body at lower temperature till the temperatures of both the bodies are the same Le are equalized
Thus levels of liquid, temperatures of the bodies are the quantities which determine the direction of flow. A quantity that determines the direction of flow of electric charge is called electric potential.
The absolute electric potential (sometimes called only potential) at a point is defined as the amount of work done in moving unit positive electric charge from infinity to that point.

The Potential difference (abbreviated as p.d.) between two points is defined as the amount of work done in moving unit positive electric charge from one point to the other

Let W be amount of work done in moving a charge of Q units from one point to the other. Then the potential difference between these two points, says V, is given by the relation

$V = W/Q$

The M.K.S. system of unit for measurement of potential difference which is in use is called volt. When I joule of work is done in moving a charge of 1 coulomb from one point to the other, the potential difference between them is equal to 1 volt.

Le. I volt

I joule 1 coulomb

SIGN OF POTENTIAL

A

B

+1

Tendency to move away from +ve charge at A

A

B

+1

Tendency to move towards ve charge at A

Consider a positive charge placed at a point. A Take another point B in its electric field. In order to find potential at point B. we shall have to imagine that a unit positive charge is moved from infinity up to the point B

However as both the charges are positive there exists a force of repulsion between them and work will have to be done against the direction of force of repulsion.

The work done is therefore positive. Thus we note that potential due to a positive charge is positive.

Now let us consider the case when a negative charge is placed at point A

In this case the unit positive charge being moved from infinity up to the point B experiences a force of attraction and moves by itself towards the point B.

Thus work is done by the force of attraction itself. which is considered negative. Thus we get that potential due to a negative electric charge is negative.

POTENTIAL DIFFERENCE DUE TO A POINT CHARGE

Consider a positive charge of Q coulomb. Take two points A and B, situated at a distance D, and D. respectively in the electric field of this charge. The potential difference between the points A and B is to be determined.
The distance between A and B is subdivided into smaller intervals by points A,. A, AA, such that the point A, is very close to A, A, is very close to A, and so on. Let d, d. d,... be the distances of points A. A A,.... from point A.
Intensity of Electric field at point A = E - Aπε K

Intensity of electric fielt at, A,
4 Q
The posts. A and A, are very close to each other as h the intensaties of electric field differ by very small amount as such the electric field between these points is assumed to be uniform.
The average intensity of electric field between points A and A, is given correctly by geometric mean which is equal to E, E
Hence we get, average intensity of electric field between points A and A. A and A
The potential difference between these two points is equal to the amount of work done in moving unit positive charge from point A, to point A.
Point A, to point A Force (Intensity)
Displacement

4K Dd, Id,-D,

Similarly we can put. Potential difference between points A, and A

Potential difference between points A, and A, Potential difference between points B and A Q 4K [4]
The potential difference between points A and B is equal to sum of all these potential differences.

0
K
Po no (2-3)
2.10 ABSOLUTE POTENTIAL DUE TO A POINT CHARGE
The absolute potential at a point situated at a distance, say d, from a charge Q is obtained by putting D, equal to d and D, equal to infinity () in above expression for potential difference.

Absolute potential 4 πε K
As is very very large number, is equal to zero. Then we get, Q Absolute potential=V=4Kd 10 오 9×10 κα
This shows that absolute potential at a point due to a charge is dependent on its distance from the charge.
The potential at a point nearer to the charge is higher than the potential at a point away from the charge.
Note: The derivation of the formulae for potential difference and absolute potential is not expected from the students. It is given here to clearly Illustrate the factors on which these quantities depend.

2.11 POTENTIAL AT A POINT ON THE SURFACE OF SPHERE

In the case of a spherical conductor although the electric charge is situated on its surface it behaves as if it is placed at its centre.
Consider a sphere of radius r given a charge of Q coulomb. Then potential at any point on the surface of the sphere is given, V = 9x10 Kr

As there is no charge inside the sphere, the potential at any point it will be the same as that at a point on its surface
All points situated on the surface of the sphere are equidistant from its centre as such every point on its surface will have the same potential.
Such surface which has the same potential at every point on it is called equipotential surface.

2.12 POTENTIAL OF THE EARTH

The earth is nearly spherical. For mathematical purposes it is assumed to be spherical. Then potential at a point on the surface of earth is given by the relation for potential of a sphere.
Let us suppose that a charge of Q coulombs is given to surface of the sphere
The value of any charge given to the surface of the earth will be very small in comparison to its radius, as such the potential of the earth is very very small and for all practical purposes it is taken equal to zero.
The absolute potential at a point is defined as amount of work done in moving unit positive charge from infinity up to that point. In practice we cannot take any point at infinity and measure absolute potential at a point due to electric charge. As such potential difference between a body and the earth is measured.
Since potential of the earth is zero, this gives absolute potential of the body.

We know that electric charge flows from a body at higher potential to a body at lower potential. In view of this all electrical circuits are earthed ie. connected to the earth
In that case if there be any leakage of current it passes to the earth and the appliances are protected from damage.

II B: Magnetism

2.13 MAGNETISM AND MAGNET

It is observed that there are some substances which possess property of attracting iron objects. This phenomenon is called magnetism and the substance possessing this property is called magnet. A magnet attracts irom, steel, nickel, cobalt

MAGNETIC POLES

The most convenient form of magnet is a bar magnes
When a bar magnet is dipped into a tray containing iron Filings and taken out, it is observed that iron filings cling to the surface of the magnet, but they are not clinging uniformly all along its surface.
The iron filings are clinging near ends of the magnet and in the central region there are no iron filings clinging to the surface of the magnet.
This indicates that the power of attraction is concentrated at points near the ends of the magnet. The points where the property of magnetic attraction appears concentrated are called magnetic poles. Thus a bar magnet has two poles.
When a bar magnet is freely suspended it settles itself in approximately north south direction. The pole facing north direction is called North Pole and the pole facing south direction is called South Pole.
N
N
S
N
S
N
S
S
Fig. 2.14.1
The poles of a bar magnet are situated near its end. One may think that if the bar magnet is cut at its centre. isolated north and south poles can be obtained. However it is observed that both the pieces of the bar magnet have two poles.

This indicates that the poles of a magnet cannot be isolated. In mathematical computations we assume that separate existence of either of the poles. This assumption is fictitious. As such an isolated magnetic pole is considered to be fictitious pole.

A bar magnet is freely suspended and north pole of other bar magnet is brought near to it. It is observed that the north pole of the suspended magnet moves away

Now south pole of the other magnet is brought near to the north pole of the suspended magnet, it is observed that the North Pole of the suspended magnet moves towards South Pole of the other magnet

These observations can be summarized as "like poles repel, unlike poles attract"

It is also observed when a magnet is brought nearer to some other iton body, it also gets magnetized.

The above observations are summarized as properties of magnet, listed below

2.15 PROPERTIES OF MAGNET

1. A magnet attracts iron, steel, cobalt, nickel.

2. A bar magnet suspended freely sets itself in north-south direction.

3. Like poles of a magnet repel and unlike poles attract.

4. Magnetic poles exists in pairs i.e. the poles of a magnet cannot be isolated.

2.16 MAGNETIC LENGTH

Magnetic equator

N

S

Magnetic axis

2/

L

Fig. 2.1

The poles of a bar magnet are not situated exactly at its ends, they are situated slightly inside the ends as shown in Fig. 2.16.1.

The distance between two magnetic poles is called magnetic length and denoted by symbol 21

The actual length of a bar magnet is called geometric length and denoted by symbol L.

It is observed that magnetic length of a bar magnet is the of its geometric length. 5

ie 21=L

MAGNETIC AXIS AND M EQUATOR

The straight line joining the poles of a bar magnet it called its magnetic axis. The perpendicular bisector of the magnetic axis is called magnetic equator.

2.18 POLE STRENGTH

The pole strength of a magnet is denoted by symbol m. The pole strength of North Pole is assigned positive (+) sign and that of the South Pole is assigned negative (-) sign. The unit of pole strength is ampere. metre (Am).

2.19 MAGNETIC FORCE

The force berween two magnetic poles of strength m, and m, separated a distance d is given by the relation P Where u is permeability of the air/free space and u, is relative permeability of the medium.

1

2.20 MAGNETIC FIELD AND INTENSITY OF MAGNETIC FIELD

The space surrounding a magnet where its effect is experienced is called magnetic field. The strength (intensity) of a magnetic field near the magnet is maximum and goes on decreasing with increase of distance from the magnet.
The intensity of magnetic field at a point is defined as the force acting on a unit North Pole imagined to be placed at that point. It is a vector quantity denoted by symbol H. Its units are newton/weber in MKS system and tesla in SI system.

Mathematically intensity of magnetic field at a point at a distance d from a pole of strength m is given by H= 1 m

2.21 MAGNETIC LINE OF FORCE

N

Fig. 2.21.1

Consider a bar magnet. Imagine a unit north pole placed at point A in its magnetic field. The unit north pole experiences force of attraction due to south pole of the bar magnet and force of repulsion due to its north pole
As a result, it moves to a point. B in the direction of resultant of these two forces. At point B it once again experiences force of attraction due to south pole and force of repulsion due to north pole and moves to another point C along the direction of resultant of these two forces.

Thus we observe that the unit north pole moves away from the north pole towards south pole along the direction of the resultant forces.
A smooth curve joining these resultant forces is called line of force. A magnetic line of force is defined as the curve along which a unit north pole moves placed in the magnetic field.
A bar magnet is kept on a cardboard and some iron filings are sprinkled over the card board and the cardboard is gently tapped.
It will be observed that the iron filings arrange themselves in the pattern of lines of force as shown in Fig. 2.21.2

2.22 PROPERTIES OF MAGNETIC LINES OF FORCE

1. The magnetic lines of force are closed curves starting from north pole and terminating in south pole o the magnet and have a direction from south pole to north pole inside the magnet.
2. The tangent drawn to the magnetic line of force at a point gives direction of the magnetic field at that poin
3. The magnetic lines of force do not intersect each other
4. The magnetic ines of force have a tendency to contract in length and expand laterally
5. The magnetic lines of force in a uniform magnetic field are equidistant parallel straight lines.

2.23 MAGNETIC FLUX

The total number of magnetic lines of force passing normally through a given area is called magnetic flux through that area.
It is denoted by symbol (pronounced as phi Its unit is weber (Wb).

2.24 MAGNETIC FLUX DENSITY (MAGNETIC INDUCTION)

The magnetic flux per unit area is called magnetic flux density or more commonly as magnetic induction and denoted by symbol B.
Thus if o be the magnetic flux passing through an area A. then Magnetic induction Magnetic flux Area
The unit of magnetic induction is weber / m (Wh/m^2). It is also called testa.
Thus I tesla 1 Wb/m^2

2.25 RELATION BETWEEN INTENSITY OF MAGNETIC FIELD (H) AND MAGNETIC INDUCTION (B)

The magnetic field intensity depends upon the magnetic induction ie magnetic flux density. The magnetic induction over an area is greater the field is stronger i.e. its intensity is more.

If magnetic induction is less, the intensity of the magnetic field is also less

II C: Current Electricity

2.26 ELECTRIC CURRENT

Electric current is constituted when electric charge flows through a conductor. The branch dealing with electric current is called current electricity.

A metallic conductor consists of a large number of free electrons. These electrons are always in a state of random motion.

They move in different directions with different speeds the number of electrons flowing in either direction is the same as a result of this the net flow of electric current in a conductor not connected to any source of e.m.f. is zero.

When the ends of the conductor are connected to a source of e.m.f., a potential difference is set up between ends of the conductor. The free electrons are subjected to an electric field set up along the length of the conductor.

Under influence of this electric field, the free electrons move in a direction opposite to that of the electric field. This causes continuous flow of electric charge through the conductor. This flow constitutes electric current. The rate of flow of electric charge is called current. Electric Current = Charge Time

Let Q be the charge flowing through a conductor in time 1. then the electric current denoted by symbol is given by the relation

Q 어

The unit for measurement of electric current is ampere denoted by symbol A. When Q1 coulomb, 1 = 1 second, 11 ampere. Thus when a charge of 1 coulomb flows through a conductor in one second electric current is equal to i ampere.

Conventional direction of cument

A

Direction of flow of electrons

Fig. 2.26.1

The electric current is constituted due to movement of negatively charged electrons. However conventionally the direction of movement of positive charge is taken as direction of movement of electric current.

Referring to Fig. 2.26.1 we observe that the direction of movement of free electrons is from B towards whereas the conventional direction of electric current is taken from A towards B.

2.27 GOOD CONDUCTOR, INSULATOR, SEMI CONDUCTOR

The electrical conductivity of a conductor depends upon the number of free electrons in it. Metals like copper, silver, aluminum have large number of free

electrons as such electric current flows with use through the conductors made using these metals. These are known as good conductors.
The substances like ebonite, glass, mica, rubber, wood do not contain free electrons as such movement of electrons is absent in them ie. no electric current can flow through them. These substances through which electrical current does not flow are called insulators.
Some substances such as germanium, silicon, carbon have comparatively less number of free electrons. Their conductivity is much less as compared to that of good conductors. These semiconductors. substances are called
Note: These definitions are given here to apprise the students about basic idea, detailed discussion is given in section II D Semiconductors.

2.28 ELECTRO MOTIVE FORCE

The flow of free electrons through a conductor constitutes electric current. The electrons while moving through a conductor experience some opposition to their flow, which is known as resistance.

In order to overcome this opposition (resistance) some work mut done by supplying some energy ke. force for pushing the electrons from a source. The cells (batteries) and generators provide this energy.
The force which supplies this energy is called electro motive force (abbreviated as em.f.). The unit for measurement of e.m.f. is volt.
When a source supplies 1 joule of energy to circulate a charge of one coulomb through a closed electric circuit, its em.. is equal to I volt
The potential difference between terminals of a cell when no current is drawn through it in external circuit is its electro motive force. When current is drawn from the cell to an external circuit the potential difference between its terminals is called potential difference.

2.29 OHM'S LAW

Ohm's law gives relation between potential difference across ends of a conductor and the current flowing through it. The law states that
The physical condition of the conductor remaining the same, the current flowing through it is directly proportional to the potential difference across its ends.
The physical conditions of the conductor are: length,
cross sectional area, temperature and material. When these conditions remain unchanged, Ohm's law hold good.
Let V be the potential difference across ends of a conductor and 1 ampere be the current flowing through it Then 1 V Or 1 KV

K is constant known as conductance of the conductor.
Rewriting the above expression we get V K
The term 1/K is replaced by letter R which is called resistance of the conductor.
R V T OIR Usually Ohm's law is remembered in this form.

2.30 UNIT OF RESISTANCE

The unt of resistance is ohm, represented by symb 2. If a current of 1 ampere flow through a conductor shes potential difference across its ends is 1 volt, its resistance is equal to 1 ohm.

1 Ohm
1 Volt 1 Ampere

2.31 SPECIFIC RESISTANCE

The temperature remaining constant, the resistance of conductor is
(a) Directly proportional to its length
(b) Inversely proportional its cross sectional area
(c) Dependent upon material of the conductor
Consider a conductor of length 1., cross sectional area A. Let R be its resistance. Then
RL R
R
(pronounced as sigma) is a constam knows as specific resistance. Its value depends upon the material of the conductor. The expression can also be written as RA RA
Let L1 and A= 1. putting these values in expression for R, we get
This enables us to define the specific resistance. The specific resistance of a material is defined as resistance of unit length of conductor having unit cross sectional arca.
Unit of specific resistance
Unit of o Unit of resistance x Unit of area Unit of length ohm-m
ohm metre-m

SPECIFIC CONDUCTANCE

R

The reciprocal of specific resistance is called specific conductance. Its unit is (ohm.m) In SI system it is siemens metre

2.33 RESISTANCES IN SERIES

12
B
V
V
Fig. 2.33.1
The series arrangement of resistance is shown in Fig. 2.33.1. In series combination of resistances, the resistances are connected end to end in succession.
The extreme ends are connected to a source of current. In this arrangement same current flows through each resistance however potential difference across each resistance is different.
The total potential difference between ends of the combination is equal to the sum of potential differences across the resistances.
Consider series combination of two resistances r, and Let V, and V, be potential differences across the resistances.
Let V be the total potential difference between ends of the combination and 1 be the current flowing through it. Then we can put V = V+V (1)
Let R, be the effective resistance of the combination.
Then according to Ohm's law V R VIR Similarly V, It VI Putting these values in Equation (1) we get V = V+V

resistances is equal to sum of resistances in the combination.
2.34 RESISTANCES IN PARALLEL
In parallel combination of resistances one end of each resistance is connected to a common point. Similarly the other end of each resistance is connected to another common point
A
www
B
V
Fig. 2.34.1
These common points are connected to a source of current. In this arrangement the potential difference across each resistance is the same as that across the combination. The current flowing through each resistance is however different.
Consider a parallel combination of resistances r, and r Let V be the potential difference between the common points.

Let 1 be the current starting from the source. Les 1, 1, be the currents flowing through the resistances r and r, respectively.

In this combination the total current I gets distributed between resistance such that 1=1+1 (1)

If Rp is the effective resistance of the combination, applying Ohm's law we can put V V Similarly 1, Iر

Putting these values in equation we get V R

$$1/R_{v} = 1/r_{i} + 1/r_{2}$$

Thus we get that the reciprocal of the effective resistance of parallel combination of resistances is equal to the sum of reciprocals of the resistances in the combination.

2.35 CONVERSION OF GALVANOMETER INTO AMMETER AND VOLTMETER

Conversion of Galvanometer into Ammeter

An ammeter is used for measurement of electric current.

It is a galvanometer modified to measure electric current. The dial of the ammeter is calibrated to read current in ampere. If the current to be measured is small calibrations are in milliamp.

S

Fig. 2.35.1

A galvanometer is converted into ammeter by connecting a low value resistance in parallel with galvanometer coil.

An ammeter is connected in series in an electric circuit to measure the electric current passing through it.

Conversion of Galvanometer into Voltmeter

Voltmeter is an instrument used to measure potential difference across a electric circuit. It is connected in parallel in a circuit between two points potential difference across which is to be measured. The dial of the voltmeter is calibrated to read volt. (or milli volt for small potential difference)

الله

Fig. 2.35.2

A resistance of high value is connected in series with the galvanometer coil to convert it into a voltmeter.

2.36 HEATING EFFECT OF ELECTRIC CURRENT

When electric current passes through a resistance wire, it experiences resistance to its flow. In order to overcome this resistance, some of the electrical energy is spent.

The electrical energy so spent gets converted into heat energy and the wire is heated. This is called heating effect of electrical current. The quantity of heat developed is given by a law known as Joule's law.

2.37 JOULE'S LAW

The amount of heat generated in a resistance wire when electric current is passed through it, is directly proportional to

(a) Square of the current flowing through the wire.

(b) Resistance of the wire.

(c) Time for which the current flows.

Consider a resistance wire of resistance R. Let 1 be the current flowing through it for t seconds. Let H be the amount of heat generated. Then according to Jooule's law

HR

Ht

H

PRI

J

Or H

J is a constant known as mechanical equivalent of heat. having value 4.2 joule per calorie ie. 4200 joule/kile calorie

Re writing above expression we get

According to Ohm's law IR = V where V is potential difference across the resistance wire.

Substituting this for IR we can also put the expression 25

H

IV J

: Semi Conductors

To have clear understanding of the band theory, difference between good conductors, semi conductors and insulators, knowledge of atomic structure is essential.

2.38 ATOMIC STRUCTURE

An atom is fundamental unit of matter. It consists of a tiny positively charged core called nucleus. The nucleus contains protons and neutrons.

The protons carry positive charge whereas the neutrons are electrically neutral ie, do not carry any charge. The total positive charge and almost entire mass (99.9%) of the atom is confined to its nucleus.

The nucleus of a atom is surrounded by electrons which carry negative charge and revolve around the nucleus in elliptical orbits. (However many a times orbits are shown by concentric circles for the sake of simplicity).

The total negative charge of the electrons is equal to total positive charge of the protons. As a result of this atom as a whole is electrically neutral.

The number of electrons in various orbits is governed by a rule. The number of electrons in an orbit is equal to 2n where n is the number of the orbit. The rule has exception that the outermost orbit cannot have more than 8 electrons.

Thus we get, Number of electrons in the first orbit = 2(1)=2 Number of electrons in the second orbit 2(2)=2x4=8 Number of electrons in the third orbit $=2(3)^2=2 \times 9=18$

The electrons situated in the inner orbits, being close to the nucleus experience greater force of attraction towards the positively charged nucleus on account which they remain confined to their orbits and cannot move away.

The electrons in the inner orbits are called bound electrons.

The energy possessed by bound electrons is much less than the energy possessed by the electrons in the outermost orbit of the atom.

The electrons in the outermost orbit being away from nucleus experience much less attraction towards it, posses more energy than electrons in the inner orbits.

It is difficult remove bound electrons from inner orbits whereas the electrons in the outermost orbits can easily be removed from that orbit as such they are called free electrons

The free electrons are also named as valence electrons The valence (free) electrons take part in chemical reactions and keep atoms of the matter bonded together.

2.39 ENERGY LEVELS AND ENERGY BANDS IN SOLIDS

We have noted that the energy possessed by electrons in the inner orbits is much less than that possessed by outer orbits or in other words energy possessed by electrons goes on increasing with increase of orbit position.

This can be shown by drawing a diagram with parallel lines, with each line indicating the level of energy possessed by electrons in various orbits.

3" Energy level

2 Energy level

1" Energy level

Fig. 2.39.1

Solids are formed when number of atoms come very close together and combine.
Now let us consider electrons in the first orbit of stom in a solid. The electrons in this orbit are influenced by presence of other atoms close by.
As a result of this, various electrons in this orbit although situated in the orbit possess slightly varying energies Le. have slightly varying energy levels.
In this case the energy level diagram of this orbit will not be a single line but a cluster of very closely situated lines. The cluster of closely simated energy levels is called energy band.
Likewise electrons in other orbits will have different bands separated from each other, as shown in the Fig. 2.39.2

Conduction Band (CB)
Band gap
Valerice Band (VB)
Second band
First band
Fig. 2.39.2
We have seen that the electrical properties of a material depend upon the number of electrons in the outermost orbit ie. the free (or valence) electrons of its atom. The energy hand corresponding to the valence electrons is called valence band.
The valence electrons of the metallic conductor are loosely attached to the nucleus. Some of them become free and although they cannot leave the metal surface jump from one atom to the other randomly.
These electrons constitute flow or conduction of electric charge. The energy level of these electrons being higher than that of electrons in the valence band, they form a different band known as conduction band
The difference between energy levels of electrons in the valence and conduction band or the separation between these bands is called forbidden energy gap (or simply band gap). It is denoted by E
2.40 CONDUCTOR
CB
VB
Very small gap
Fig. 2.40.1
The band gap between valence band and conduction band is very small in some materials.

In metals such as copper, silver, aluminum these bands overlap each other and there is no forbidden gap. Due

to this a very large number of free electrons available for conduction of electrical charges.

Even a small potential difference is enough ins movement of free electrons in conduction band. The electric charge ie. current moves easily and speedily conductors made up of these metais.

Thus the metals through which the clectric charge/current moves easily and speedily are called conductors of electric charge.

2.41 INSULATOR

In some materials there is wide gap between the valence and conduction hand and there are no electros in the conduction band

CB

Forbidden gap +

VB

Fig. 2.41.1

At normal temperature the thermal energy is insufficient to push the electrons from valence hand into conduction hand.

In absence of free electrons in the conduction band there is no flow of electric charge in these materials. These materials are called insulators.

The material through which there cannot be flow of electric charge is called insulator. Wood, plastic, rubber, chonite are examples of insulators.

2.42 SEMICONDUCTOR

Bands

overdap

CB

Small gap

IN

VEB

Fig. 2.42.1

In some materials the band gap between valence and consduction bands is small (less than 3 V

In these materials, even at ordinary room temperature some electrons from valence band acquire energy enough to jump into conduction hand and flow of such electric charge takes place.

However the number of electrons jumping from valence band to conduction hand being small the flow of electric charge through such materials is much less than that of the conductors. These materials are called semi conductors: Thus semi conductors are the materials have conductivity less than that of conductors and more than that of insulators.

2.43 TYPES OF SEMICONDUCTORS

Fig. 2.43.1

Consider two solids: Silicon (Si) and Germanium (Ge). The atomic numbers of silicon and germanium are 14 and 32 respectively.

The distribution of electrons in orbits of a silicon atom is 2, 8, 4 and the distribution of electrons in germanium atom is 2, 8, 18, 4.

This shows that the number of atoms in the outermost orbit of both the atoms is the same, equal to 4. The outermost orbit of an atom can hold maximum 8 electrons. When it holds 8 electrons in the outermost orbit, it becomes stable. In order to achieve stability the silicon and germanium atoms form covalent bonds with the electrons in the outermost orbit of the neighboring atoms.

The resultant lattice is as shown in Fig. 2.43.2. This lattice makes the atoms extremely inactive, as there are no free electrons. Pure silicon and germanium are therefore very poor conductors of electric charge ie electricity.

There are two types of semiconductors Intrinsic semiconductors and Extrinsic semiconductors.

2.44 INTRINSIC SEMICONDUCTORS

A semiconductor made of semiconductor in extremely pure form is called intrinsic semiconductor.

In this case the free electrons necessary for conduction of electric charge are obtained by subjecting the pure silicon or germanium to heat or light energy. The energy so supplied breaks the covalent bond of the atoms and some electrons are set free which enable them to conduct electricity to a small extent

2.45 EXTRINSIC SEMICONDUCTOR

A semiconductor in which a small amount of suitable impurity (e. some other suitable substance) is added to set free some electrons is called extrinsic semiconductor.

The process of adding an impurity in order to increase its conductivity is called doping. The impurity added is called doping agent. The doping agent is used in extremely small amounts.

For doping silicon and germanium either a pentavalent or a trivalent impurity is used. Indium (Ia) has atomic number 49 and its electron distribution is 2,8,18,18.3, as such it is trivalent.
Atomic number of antimony (Sb) is 51 and its electron distribution is 2, 8,8,18,18,5 as such it is pentavalent. Both indium and antimony are used as doping agents

2.46 MINORITY AND MAJORITY CHARGE CARRIERS

Semiconductors) Pg ho (2-16)

Minority and Majority Charge Carriers

The particles that are free to move and carry electric charge are called charged particles. In semiconductors electrons (which are negatively charged) and holes (which are positively charged) are the charge carriers.
The charge carriers which are present in a small quantity are called minority charge carriers. They cause very small amount of electric current in a semiconductor
The charge carriers which are present in large quantity are called majority charge carriers. The majority charge carriers carry most of the electric charge and are mainly responsible for flow of electric current in a semi conductor.

2.47 STATIC AND DYNAMIC RESISTANCE

Static Resistance

The resistance offered by a diode when direct current (D.C.) is applied to it is called static resistance.

Dynamic Resistance

The resistance offered by a diode when alternating current (A.C.) is applied to it is called dynamic resistance.

2.48 N-TYPE SEMICONDUCTOR

Ge
Ge
Free electron

Consider doping of germanium crystal with pentavalo antimony. When antimony is added to germanin, of the germanium atoms in the crystal lattice replaced by antimony.
Four electrons of antimony in its ounermend orbit fo covalent bonds with valence electrons of fo neighboring germanium atoms. The fifth valenc electron of the antimony remauss free
The addition of antimony helps increase in number of electrons available for conduction and the dopet germanium acts as a good conductor

When a potential difference is applied an germanium crystal, the electrons move towarth the positive terminal and thus electric cunest constituted
The antimony has donated one free electron germanium as such it is called donor. The electrical conductivity is set into germanium due to motion negatively charged electrons as such is called N-type semiconductor.

2.49 P-TYPE SEMICONDUCTOR

Consider doping of germanium crystal by trivalen indium. When indium is added to the germanian crystal one germanium atom in the crystal lattice a replaced by indium atom.

Three valence electrons of indium form covalent bond with three neighboring germanium crystal Consequently one of the covalent bond round cact indium atom is short of electron.

Ge
Sb
Hole

The absence of one electron leaves a gap which is called hole. When potential difference is applied across germanisto crystal, one electron from the neighboring covalent jumps into this hole, leaving behind a hole in the atom from which it has jumped

This hole is filled by an electron in the next bond and so on the process cominues. In this case the electrons move in a direction and the holes move in a direction opposite to that of the electrons

The absence of electron is equivalent to formation of positive charge. When a potential difference is applied across the germanium crystal, the holes move in the direction of the applied electric field and electric current is set up.

Thus current is set up due to movement of positive charge; hence this type of semiconductor is called P- type of semiconductor.

In this case the doping agent is accepting the electrons from the neighboring atoms of the doped material as such it is called acceptor.

2.50 DISTINCTION BETWEEN N-TYPE AND P-TYPE SEMICONDUCTORS

The following are the points of distinction between N type and P type semiconductors.

Sr. No.
N-type semiconductor
1.
These are obtained when small quantity of a pentavalent impurity is added to a pure semiconductor.

2.
The impurity added provides free electrons as such it is called donor
P-type semiconductor
These are obtained when a small quantity of a trivalent impurity is added to a pure semiconductor.
The impurity added receives free electrons as such it is called acceptor.

N-type semiconductor
P-type semiconductor
3.
Free electrons carrying negative charge are available in these semiconductors and electric current is set up due to movement of electrons, as such it is called N-type semiconductor.
Holes carrying positive charge are available in these semiconductors and electric current is set up due to nervement of posutively charged holes, as such these are called P-type semiconductors.
2.51 P-N JUNCTION DIODE
Anode
P
N
Cathode
(a)
Pg no (2-17)
(b)
Fig. 2.51.1
A thin crystal of germanium or silicon is taken. One half of this crystal is doped with a pentavalent donor impurity and the other half is doped with trivalent acceptor impurity.
The crystal is covered by a sealing compound. The half portion doped with donor impurity has excess of free electrons in it. It is called N region.
The other half doped with acceptor has excess of holes in it i.e. positive charge. It is called P region. The border between the two regions is called junction. The arrangement is known as P-N junction diode. It is symbolically represented as shown in Fig. 2.51.1(b) above:
P
N
P
N

Depletion layer

At the junction come free electrons from N region diffuse imo P. region and some holes from P region diffuse into N region.
The layer near junction is thus depleted of free charges. It is called depletion layer. The diffusion or crossing of electrons and holes develops a potential difference across the junction
This potential difference prevents continuous diffusion of electrons and holes across the junction, hence it is called herrier potential
The potential barrier is equal to 0.7 V for silicon diode and 0.3 V for germanium diode. When no external source is connected to the diode it is called unbiased diode
The P-region end of the diode is called anode and N region end is called cathode.
2.52 FORWARD BIASED DIODE
Holes
Electrone
00
000
Conventional current
Electron flow
A
Fig. 2.52.1
V
Fig. 2.52.2
Consider the case when a external source is connected to P-N junction diode. The positive terminal is connected to the P region and negative terminal is connected to N region. (Fig. 2.52.1). This type of conection is called forward biased
When the potential difference of the external source is greater than the barrier potential, the holes in the P region move towards the N region and the electrons in

the N region move towards the P region through junction
The electrons in the N region are replaced by electrons arriving from the negative terminal of external source. The electrons leave the P regre thereby

creating holes in that region. Thus then continuous flow of electric charge ie. current tin the стесмин.

In a forward biased diode very small currem flou through the circuit when the potential differma applied across the diode is below the barrier potemial

When the applied potential difference crosses the barrier potential, the current in the circuit increme rapidly. The nature of the graph between applied potential against current flowing in the circuit is a shown in Fig. 2.52.2.

2.53 REVERSE BIASED DIODE

P

N

Fig. 2.53.1

Beak down voltage

V

Fig. 2.53.2

Consider a circuit in which the negative terminal of the source is connected to P region and the positive terminal of the source is connected to N region of the diode. (Fig. 2.53.1)

This type of connection is called reverse biased. In reverse hiased diode the holes in the P region an attracted and move towards the negative terminal of the source.

The electrons in the N region are attracted and move towards positive terminal of the source

Thes it is observed that charge carriers move away nom the junction and the width of the depletion layer increases. A very small amount of charge carriers are produced in the depletion layer due to thermal energy and their movement constitutes current

This current is called leakage current. If the applied potential difference in reverse biased diode is increased continuously, it does not result in increase of current.

However when the potential difference crosses certain value, the current increases suddenly and the diode gets damaged. This is called break down of the diode.

The potential difference at which diode break down occurs is called break down voltage. The nature of the graph of current against applied potential difference is as shown in Fig. 2.53.2.

2.54 APPLICATIONS OF P-N JUNCTION DIODE

• The following are main application of a P-N junction diode

In alternating current (AC) the direction of current continuously changes.
When current flows in one direction only it is called direct current (D.C.).
If a P-N junction is included in a circuit of AC source, it allows flow of electric current only when there is forward bias and there is no current when bias is reversed due to change in the direction of the current from the source.
As a result of this the output is only in one direction i.e. AC is converted into DC. This action is called rectification and the circuit using this is termed rectifier. Thus we get that a diode can be used as a rectifier.
The P-N junction diode in reverse biased condition is sensitive to light from a range from 400 nanometer to 1000 nanometer, which includes visible light.
Therefore it is used as a photodiode.
It is used as a solar cell.
P-N junction diode in forward bias condition is used in LED lighting applications.
The voltage across P-N junction diode is used to create temperature sensors.

2.55 HALF WAVE RECTIFIER

... Pg no (2-19)

D
M
ac input 230 V, 50 Hz
N
B
Circuit diagram for half wave rectifier
VA
a.c. input voltage
V
d.c. output voltage
time
time
+VA
Input Output waveforms for half wave rectifier
Fig. 2.55.1

P-N junction diode conducts only when it is in forward bias condition. Half wave rectifier is based on this principle and converts A.C. into D.C.
Consider a single phase half wave rectifier. In this arrangement a single diode is connected in series with a load resistor.

A.C. input from secondary coil terminals of a step down transformer is applied to the diode.
In A.C. during half cycle, current flows in one direction and in the next half cycle direction of flow of current is reversed.
During positive half of the cycle, the upper end of the secondary coil of the transformer is positive with respect to its lower end and the diode is in forward bias condition and gives output voltage across the load resistor.
In the next half cycle which is termed negative cycle. the lower end of the secondary coil of transformer positive with respect to upper end which input is negative, the diode becomes reverse biased as such there is no output from it ie the diode does not conduct any current.

There is some negative current, however it is very small hence neglected.
When positive cycle again comes, the diode gets forward biased and gives output. Thus we note that there is flow of current during alternate half cycles.
The D.C. is obtained during half the cycle as such this arrangement is called half wave rectification.
The D.C. output is intermittent and its value various
from zero to certain maximum as seen from the graph. However as frequency of AC is high, these variations are generally not noted.
The half wave rectifiers are less efficient in comparison with full wav rectifier.

2.56 PHOTO DIODE

PN
Pg no (2-2
N
Fig. 2.56.1

A photo diode is a modified form of P-N junction diode. In this diode a small transparent window is kept to expose the junction to light radiations. This diode is given reverse bias.
When light enters the depletion region at the junction and light photons possess energy greater than the energy gap, electron-hole pairs are generated. These electron-holes flow under influence of reverse bias and a small current of the order of µA flows in the circuit.
The strength of this current depends upon the intensity of the incident light and it is independent of reverse bias. The photo diodes are symbolically represented as shown in Fig. 2.56.1.

2.57 APPLICATIONS OF PHOTO DIODE

The following are some of the applications of photo diode

A photo diode is used in

1. Optical communication system
2. Automotive devices
3. Medical devices.
4. Solar cell panels
5. Smoke detectors.
6. Compact disc players, televisions
7. Camera light meters and in street lights
8. Logic circuits.

2.58 ILLUSTRATIVE EXAMPLES

Ex. 2.58.1: Two electric charges of 5 μC and 20 μ placed 50 cm apart in air. Calculate the force between them

Soln.:

We have Q_1 = 5 μC = 5 x 10°C, Q_2 = 20 μC = 20 × 10°C, K=1 and d = 50 cm = 0.5 m = 5x10m F= 9x10 QQ Kd Putting the values of quantities we get, F = 9x 10x5x10x20x10 1x05 100x10 9x 10x10 25 x 10 AF F9x4x10 = 36 x 10 = 3.6 N

Ex. 2.58.2: The force between two equal like charges placed 0.1 m apart in air is 2.4 N. What will be the forer between them when they are placed 5 cm apart in a mediun of dielectric constant 2.5"

Soln.: We have Force between charges in first case F_1 = 2.4 N when K1, d=0.1 m and QQ=Q In second case K = 2.5 and d = 5 cm = 5 x 10m We have F 9x10° QQ Kd F, 2.49x10 QXQ (0.1)