

Unit: 4

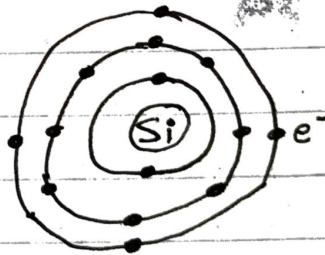
Semiconductor Materials

1. Semiconductor: The word Semi-conductor is composed of two words - Semi and Conductor. Semi means not completely while conductor mean something, which can conduct electricity.

A semiconductor is a material that has intermediate conductivity between a conductor and an insulator. It means that it has unique physical properties somewhere in between a conductor like aluminium and insulator like glass.

i.e. Semiconductor material is one whose electrical properties lie in between those of insulators and good conductors.

Example are: Silicon and Germanium.
and, Boron, Gallium, Arsenic



In a Silicon atom there is 4 electrons in the valence shell (outermost orbital)



⇒

(*) Semiconductor Electrical Nature

A semiconductor is a substance which has resistivity (10^{-4} to $0.5 \Omega m$) in betⁿ conductor & insulator. It is neither conductor nor insulator.

Ex: Germanium, Silicon, Selenium, Carbon etc.

The electrical nature of the semiconductor's are as follows:-

1) The resistivity of semiconductor is less than an insulator but more than a conductor.

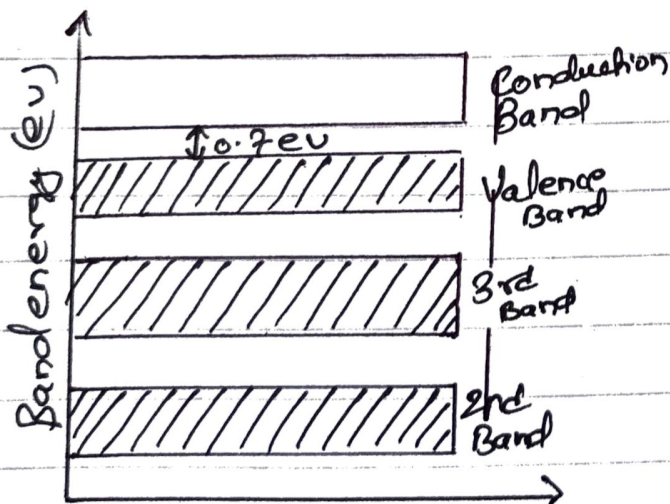
- ② Semiconductor have negative temperature coefficient of resistance
- ③ When a suitable metallic impurity is added to a Semiconductor, its current conducting properties change appreciably.

* Band Structure of Group IV materials, Energy gap.

We know that Semiconductor is a material whose resistivity lies betⁿ conductor and Insulator.

The resistivity is of the order of 10^{-4} to $0.5 \Omega \cdot m$. However a S.C can be defined on the basis of energy bands as under:-

A S.C is a substance which has almost filled valence band & nearly empty conduction band with a very small energy gap ($\approx 1 \text{ eV}$) separating the two.



Germanium
fig (a)

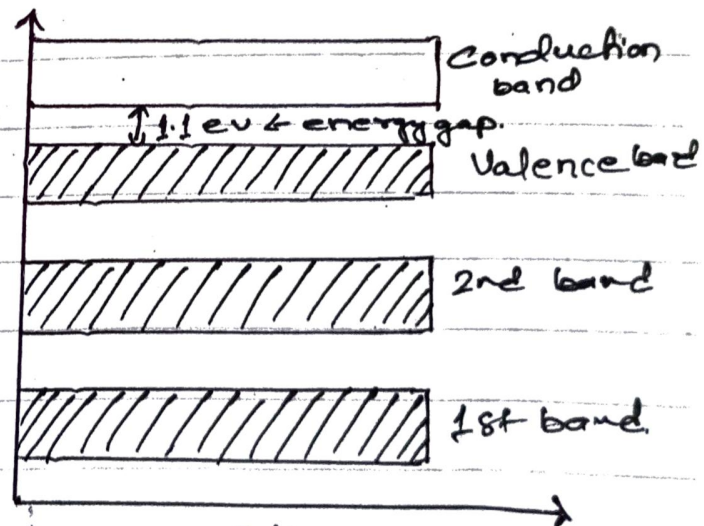


fig (b) Silicon.

Fig (a) and fig (b) shows the energy band diagrams of germanium & Silicon respectively. It is seen that forbidden energy gap is very small, being 1.1 eV for Silicon and 0.7 eV for germanium. So, small energy is needed by their valence electrons to cross over to the conduction band. At room temp^r. Some of the valence electrons may ~~required~~ required sufficient energy to enter into the conduction band. At this temp^r. the number of free electrons available is very small. Therefore at room temperature, a piece of germanium or Silicon is neither a good conductor nor an insulator. Therefore such substances are called semiconductor.

3.

* Atomic Structure of Silicon:→

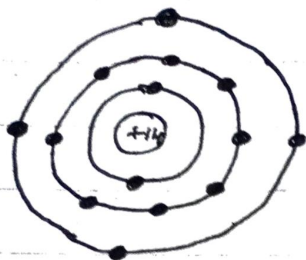
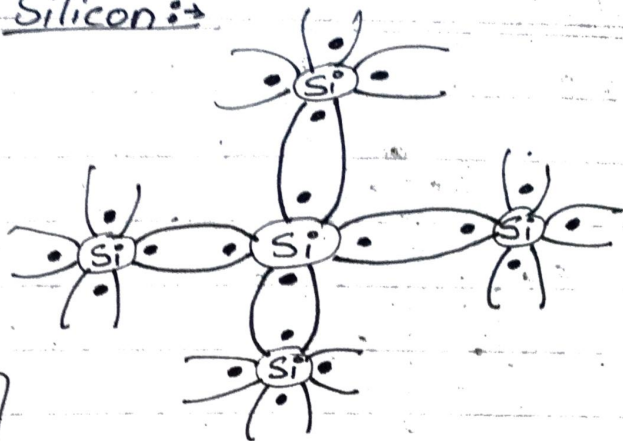


Fig (i)

K	L	M	N
2	8	4	



Atoms of every element Fig (ii) are held together by the bonding action of valence electrons. This bonding is due to the tendency of each atom to complete its last orbit by acquiring eight electrons in it. However, in most of the substances, the last orbit is incomplete i.e. the last orbit does not have eight electrons.

This makes atom active to enter into bargain with other atoms to acquire eight electrons in the last orbit. To do so, the atom may lose, gain or share valence electrons with other atom. In semiconductors bonds are formed by sharing of valence electrons such bonds are called Co-valent bonds.

The atomic number of Silicon is 14. Therefore it has fourteen protons.

→ It has 4 valence electrons i.e. it is a tetravalent element.

from fig(ii) shows how various Silicon atoms are held together through Covalent bonds.

⊗ Atomic Structure of Germanium:-

Ge 32 = 2, 8, 18, 4.

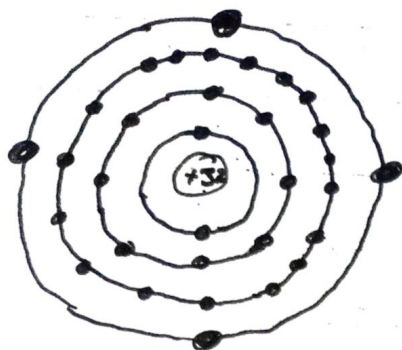


Fig: I

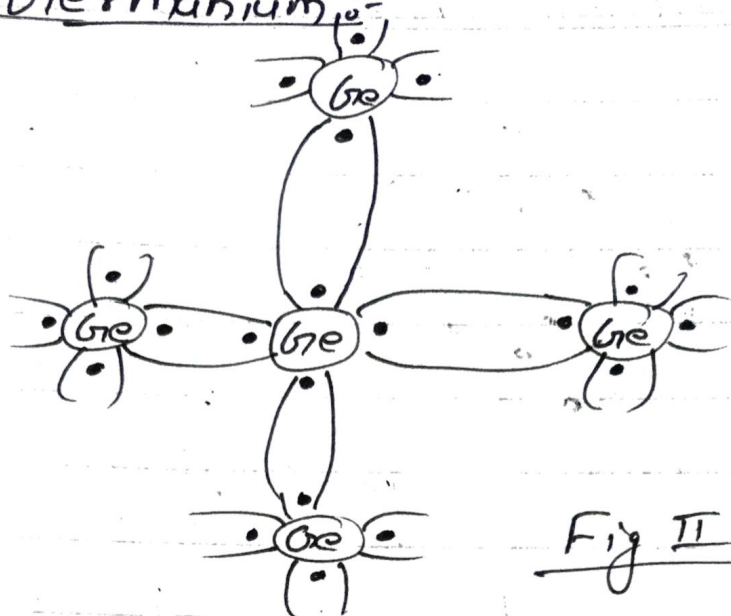


Fig II

The atomic no. of Germanium is 32. Therefore it has 32 protons and 32 electrons.

2 electrons in the 1st orbit.

8 " " " 2nd "

18 " " " 3rd "

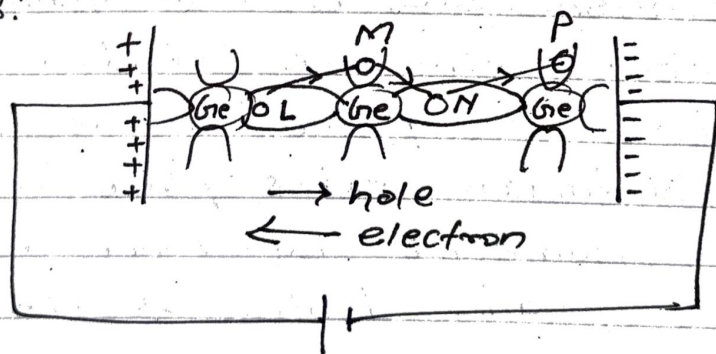
4 " " " 4th " or Valance orbit

as shown in fig(I). It is clear that Germanium atom has four valence electrons, i.e. it is also tetravalent element.

fig(II) shows how the various Germanium atoms are held through covalent bonds.

④. Formation of Electrons and holes.

At room temperature ~~some~~ some of the covalent bond in pure S.C. breaks setting up free electrons. When the electric field is applied, the free electrons flow constituting electric current. At the same time, another current, the hole current also flows in the S.C. when covalent bond is broken due to thermal energy the removal of one electron leaves a vacancy i.e. a missing electron in the covalent bond. This missing electron is called a hole which acts as +ve charge. For a electron set free, one hole is created. Therefore thermal energy create electron-hole pairs. The current conduction by hole can be explained as follows:

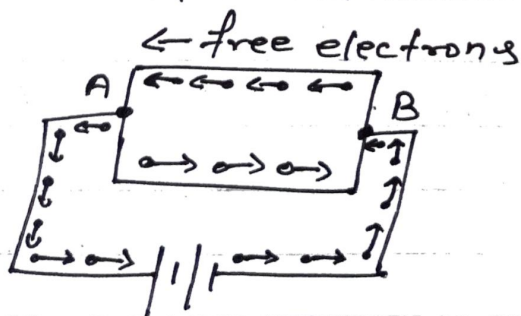


Suppose the valence electron at O.L. as shown in fig above has become free electron due to the thermal energy. This creates a hole in the covalent bond at O.L.

A valence electron (say at M) from neighbouring covalent bond ~~becomes~~ moves to fill in the hole at L. This results in the creation of hole at M. Another valence electron (say at N) in turn may leave its bond to fill the hole at M, thus creating a hole at N. Thus the hole having +ve charge has moved from L to N i.e. towards the -ve terminal of supply. This constitutes the movement of valence electrons from one covalent bond to another bond.

* Intrinsic Semiconductor:

A semiconductor in an extremely pure form is known as intrinsic semiconductor. In an intrinsic S.C, at room temperature hole-electron pairs are created when electric field is applied across it, the current conduction takes place by two processes, namely: by free electrons and holes as shown in fig:



The free electrons are produced due to the breaking of some covalent bonds by thermal energy. At the same time holes are created in the covalent bonds, when the electric field is applied, conduction through the S.C is by both free electrons and holes. Therefore, the total current inside the S.C is the sum of current due to the free electrons & holes.

It may be noted that current in external wires is fully electronic i.e. by electrons. Holes being +vely charged move towards -ve terminals of the supply. As the hole reaches the -ve terminal B, electrons enter the S.C crystals near the terminal & combine with holes, thus cancelling them. At the same time, the loose electrons near the +ve terminal A are attracted away from their atoms into the +ve terminal. This creates new holes near the +ve terminal which again drift to the -ve terminal.

* Extrinsic Semiconductor:

The intrinsic semiconductor has little conduction capability at room temp^r. To be useful in electronic devices the pure semiconductor must be altered so as to significantly increase its conductivity. This is achieved by adding a small amount of suitable impurity to a semiconductor, it is then called extrinsic semiconductor.

The process of adding impurities to a semiconductor is known as doping. The purpose of adding impurities is to increase either the no. of free electrons or holes in the S.C. crystal. If a pentavalent impurity (having 5 valence electron) is added to the S.C., a large number of free electrons are produced in the S.C. On the otherhand, adding a trivalent impurity (having 3 valence electron) creates a large number of holes in the S.C. crystal.

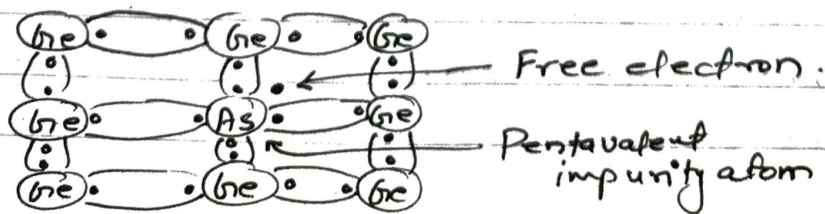
Depending upon the types of impurity added extrinsic S.C. are classified into

- (1) N-type Semiconductor (Donor) N
- (2) P-type semiconductor. (Acceptor) P

* N-type Semiconductor :

When a small amount of pentavalent impurity is added to a pure s.c, it is known as N-type s.c.

The addition of pentavalent impurity provides a large no. of free electrons in the s.c crystal. Typical example of pentavalent impurities are arsenic (At no. 33) & antimony (At no. 51). Such impurities which produce N-type s.c are known as donor impurities because they donate or provide free electrons to the s.c crystal. We know that Germanium atom has four valence electrons when a small amount of pentavalent impurity like arsenic is added to germanium crystal a large no. of free electron become available in the crystal. The reason is simple, arsenic being Pentavalent atom i.e. it has 5 valence electrons. An arsenic atom fits in germanium crystal in such a way that its four valence electrons form covalent bond with four germanium atoms. The fifth valence electron of arsenic atom finds no place in covalent bond & is thus free, as shown in fig.



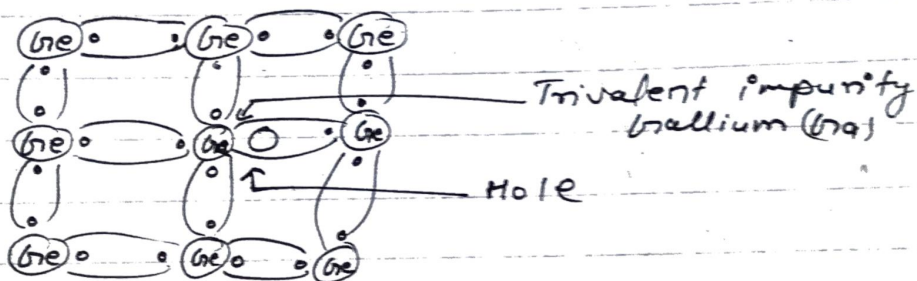
* P-type S.C.:

When a small amount of trivalent impurities is added to a pure S.C., it is called P-type S.C.

The addition of trivalent impurity provides a large number of holes in the S.C.

Typical example of trivalent impurities are Gallium (At. no. 31) and Indium (At. no. 49)

Such impurities which produce P-type S.C. are known as acceptor impurities, because the holes created can accept the electrons.



When a trivalent impurity like gallium is added to germanium crystal, there exists a large number of holes in the crystal. Each atom of gallium fits into the germanium crystal but now only three covalent bonds can be formed.

It is because three valence electron of gallium atom can form only three single covalent bonds with three germanium atoms as shown in fig. above. In the fourth covalent bond, only germanium atom contribute one valence electron, and 'Ga' all three valence electrons are already

engaged in the covalent bonds with its neighbouring germanium atoms. In other words, fourth bond is incomplete being short of one electron. This missing electron is called a hole. Therefore for each gallium atom added one hole is created. A small amount of gallium provides millions of holes.

⊗ Electrical Conduction in Semiconductor:-

(a) Conduction in N-type Semiconductor:

The current conduction in an N-type S.C. is due to free electrons & is called N-type or, electron type conductivity.

Fig below shows conduction in N-type Semiconductor.

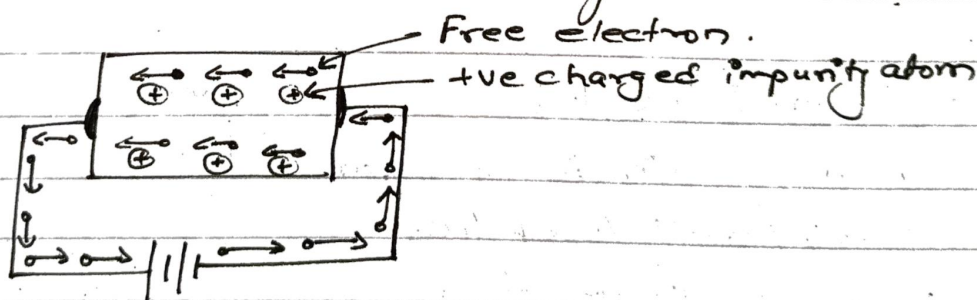
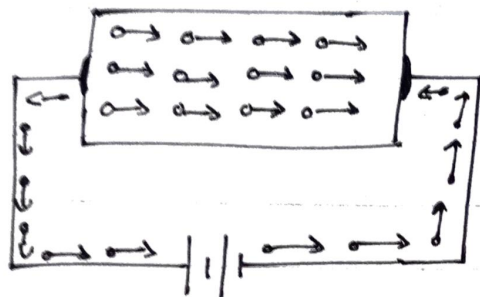


Fig: Conduction due to electron in N-type S.C

When P.d. is applied across it, the free electron will be directed towards the +ve terminal constituting electronic current. As current flow through the crystal is by free electron which are carrier of -ve charge. It may be noted that conduction is just as in ordinary metals like Copper.

b) Conduction in P-type Semiconductor:

The current conduction in a P-type S.C. takes place due to holes & is called P-type or, hole type conductivity. Conduction in P-type S.C. is explained with the help of figure below.

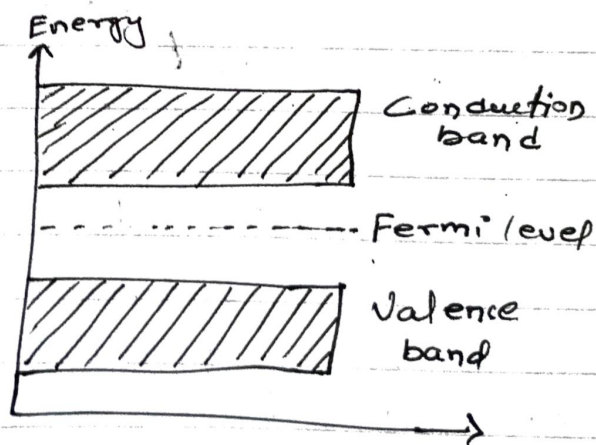


When P.d. is applied to the P-type S.C., the holes are shifted from one covalent bond to another. As the holes are +vely charged, they are directed towards the -ve terminal, constituting what is known as hole current.

* Fermi level:

In an intrinsic semiconductor, Fermi level lies in the middle of the energy gap, i.e. midway between the conduction band and valence band.

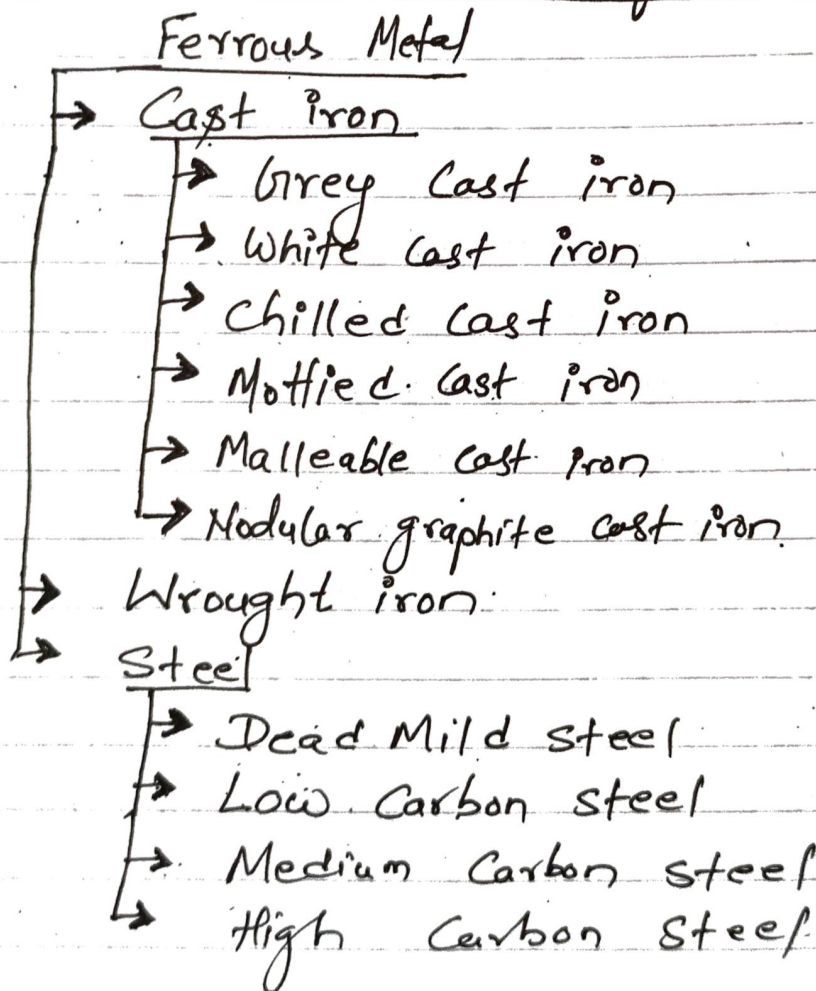
It is denoted by E_F .



1.1 Classification based on Ferrous material & Non-Ferrous material:

* Ferrous Metal: The ferrous metal are those which have the iron as their main constituent, Such as : ~~Cast~~ iron, Wrought and Steel.

* Ferrous Metal are classified as:



⊗ Non-Ferrous Metal:- The non-ferrous metal are those which have other metal than iron as their main constituent. Such as in Copper, aluminium, brass, tin, zinc etc.

⊗ The various non-ferrous metals which are used in engineering practice are aluminium, copper, lead, tin, zinc, nickel, etc and their alloy.

Cast Iron:

* Characteristics or Properties:

- It is a brittle material.
- Its cost is low and good casting properties.
- It has high compressive strength.
- It has high resistance to wear.
- It should have well machinability.

* Uses: It is used for machine tools, automotive cylinder blocks; pipes and pipe fittings.

Wrought iron

composition

- Carbon = 0.02%, Silicon = 0.12%
- Sulphur = 0.018% & rest is iron.

* Characteristics or, properties :

- a. It is tough metal.
- b. It is a malleable material
- c. It has also ductile property.
- d. It can be easily forged or, welded.

* Use : It is used for chains, Crane hooks, railway coupling, water and steam pipe.

Steel

* Characteristics or, Properties :

- a. The Steel becomes harder and tougher as its carbon content increases.
- b. It has better compression as well as tensile strength.
- c. It can be easily forged & welded.
- d. It cannot be easily hardened and tempered.
- e. Its melting point is between 1300°C & 1400°C .
- f. It absorbs shocks.

* Uses : The various uses of steel are in motor body, sheet metal, tin plate, boiler plates, structural steel, rails, hammers, large stamping & pressing dies, springs, chisels, saw, wood working tools etc.

Characteristics or, Properties of good Metal:

- a. It should have low Coefficient of friction.
- b. It should have good wearing qualities
- c. It should have ability to withstand bearing pressure.
- d. It should have ability to operate satisfactorily with suitable lubrication.
- e. It should have sufficient melting point.
- f. It should have high thermal conductivity.
- g. It should have non-corrosive properties.
- h. It should be economic in cost.
- i. It should have high electrical conductivity.

imp

1.12 Electrical characteristics & typical application of Commonly used non-Ferrous materials and their alloy [copper, aluminium, brass, bronze, silver, gold]

*. The Electrical characteristics / Properties of Non-Ferrous Metals are:

1. Resistivity: The materials should have low resistivity.
2. Temperature coefficient of material should be low
3. It should have high resistance to Corrosion in order to withstand Corrosion.

4. It should have high thermal conductivity.
5. It should have high electrical conductivity.
6. It should have high mechanical strength in order to withstand their own weight.
7. It should have high melting point.
8. It should have low specific gravity.
9. It can be easily rolled & drawn.
10. It should be economical.

Copper

* Characteristics:

- a. It has highest electrical conductivity next to silver.
- b. It is good conductor of electricity.
- c. It has high ductility.
- d. It has fair resistance to corrosion.
- e. It has good mechanical strength.
- f. It can be easily soldered and welded.

* Uses:

- a) Pure copper is used for the winding of electrical machines like motor, transformer.
- b) It is used for long span transmission line.
- c) It is also used for making electric wires & cables.

* Copper alloy:

The copper alloy are broadly classified into the following two groups:

- 1) Copper - zinc alloys [Brass]
- 2) Copper - tin alloys [Bronze]

4. Brass: The most widely used copper-zinc alloy is brass. There are various types of brasses depending upon the proportion of copper and zinc. By adding small quantities of other element the properties of brass may be greatly changed. For example, the addition of lead (1 to 2.1%) improves the machining quality of brass. It has greater strength than that of copper, but a lower thermal and electrical conductivity. Brasses have very good resistance to atmospheric corrosion & can be fabricated and can be easily soldered and can be also be electroplated with metals like nickel and chromium.

The following table shows the composition of various types of brasses:

S.No	Types of Brasses	Composition in %	Uses
1.	Cartridge brass	Copper = 70% Zinc = 30%	Used for cold rolled sheets, wire drawing, Pressing & tube manufacture.
(*) 2.	Yellow brass	Copper = 66% Zinc = 33%	It is suitable for not working by rolling, extrusion & stamping.
3.	Leaded brass	Copper = 62.5% Zinc = 36% lead = 1.5%	These are used for automobile parts.
4.	Admiralty brass	Copper = 88 70% Zinc = 20 30% Tin = 1%	These are used for plates, tubes etc.
5.	Naval brass	Copper = 59% Zinc = 40% Tin = 1%	It is used for marine casting.
6.	Nickel Brass	Copper = 60% Zinc = 20-35% Nickel = 5-35%	It is used for valves, plumbing fittings, automobile fitting, type writer parts & musical instruments.

Imp

2.) Bronze:

It is the alloy of Copper and tin. The useful range of composition is 75 to 95% of copper and 5 to 25% of tin. The metal is comparatively hard, resists surface wear, and can be shaped or rolled into wires, rods & sheets very easily. In corrosion resistant properties, bronzes are superior to brasses.

Some of the common types of bronzes are as follows:

- a. Phosphor bronze.
- b. Silicon bronze.
- c. Beryllium bronze.
- d. Manganese bronze.
- e. Aluminium bronze.

a. Phosphor bronze:

It is an alloy of Copper, tin and small percent of phosphorous. The composition of tin, copper and phosphorous is:

Copper = 87 - 90%

Tin = 9 - 10%

Phosphorous = 1 - 3%

When bronze contains phosphorous, it is called phosphorous bronze. Phosphorous increases the strength of this and ductility. The tensile strength of this alloy varies

Tensile strength: the resistance of a material to breaking under tension
or, T. strength of a material is the maximum amount of tensile stress that it can take before failure.

from 215 MPa [Mega Pascal] to 280 MPa. It is used for bearing, worm wheels.

b. Silicon bronze:

It is an alloy of Copper, Silicon & small percentage of manganese. The composition is

Copper = 96%

Silicon = 3%

Manganese = 1%

It has good corrosion resistance & combined with higher strength. It can be cast, rolled stamped, forged and pressed either hot or cold. It can also be welded by all the usual methods.

It is used for boilers, tanks, stoves where high strength & good corrosion resistance is required.

c. Beryllium Bronze: It is an alloy of copper and beryllium. The composition of beryllium and copper is

Copper = 97.75%

Beryllium = 2.25%

Yield point: is load at which a solid material being stretched begins to flow & change shape permanently & deforming.

It has high yield point, high fatigue limit & excellent cold & hot corrosion resistance. It is particularly suitable material for springs, heavy duty electrical switches, crank shaft & bearings.

d. Manganese bronze: It is an alloy of Copper, Zinc & small percentage of manganese.

Composition:

Copper = 60%

Zinc = 35%

Manganese = 5%

Plunger:-
a piston like reciprocating part moving within the cylinder of pump or hydraulic device.

This metal is highly resistant to corrosion. It is harder and stronger than phosphor bronze. It is generally used for brushes, plungers, feed pumps, rods etc.

e. > Aluminium bronze: It is an alloy of Copper and aluminium. The composition of Copper & aluminium is:

Copper = 92-94%

aluminium = 6-8%

The maximum tensile strength of this alloy is 450 MPa. They are most suitable for making components exposed to severe corrosion condition. Aluminium bronzes are widely used for making gears, propellers, condensers, ~~tools~~, pump components etc.

Specific gravity = density of substance

density of ref. substance
water/air.

Aluminium

It is white metal produced by electrical processes from its oxide (alumina), which is formed by a clayed mineral called bauxite. It is light metal having specific gravity 2.7 and melting point 658°C . The tensile strength of metal varies from 90 MPa to 150 MPa.

In its pure form, the metal would be weak and so, that it can be cut by knife.

But when it is alloy with other metal with small percentage, it becomes hard and rigid. So, it can be formed, drawn, turned, cast, forged & die cast.

V.V.I

* Aluminium alloy: The aluminium may be alloyed with one or more other elements like Copper, magnesium, manganese, Silicon & nickel. The addition of small quantity of alloying elements converts the soft and weak metal into hard & strong metal, while still retaining its light weight. The main aluminium alloys are discussed below:

1. Duralumin: It is an alloy of Copper, manganese, magnesium. Its composition are as follows:

Copper = 3.5 - 4.5%, magnesium = 0.4 - 0.7%
manganese = 0.4 - 0.7% & remaining is aluminium

This alloy possesses maximum tensile strength upto 400 MPa.

It is widely used for forging, stamping, bars, sheets, tubes & rivet. Due to its high strength & light in weight, this alloy may be used in automobile & air craft components. It is also used in manufacturing of connecting rods, bars, rivets, pulley, etc.

2. Y-alloys: It is also called Copper-aluminium alloys. The addition of Copper to pure aluminium increases its strength & machinability. The composition of this alloy is as follows:

Copper = 3.5 - 4.5%

Manganese = 1.2 - 1.7%

Nickel = 1.8 - 2.3%

Silicon, Magnesium, Iron = 0.6% each.

& the remaining is aluminium.

It is mainly used for cast purpose, but it can also be used for forged components.

Y-alloys has better strength than duralumin at higher temperature, therefore it is much used in air craft engines for cylinder heads and piston.

3. Magnalium: It is made by melting the aluminium with 2 to 10% magnesium in a vacuum and then cooling it in a vacuum or, under a pressure of 100 to 200 atmospheres. It also contains about 1.75% copper. Due to its light weight and good mechanical properties, it is mainly used for aircraft and automobile components.

4. Hindalium: It is an alloy of aluminium and magnesium with a small quantity of chromium. It is a trade name of aluminium alloy produced by Hindustan Aluminium Corporation Ltd, Renukot (U.P.).

V.V.9

1.13 Carbon as an electrical material & its product with application: Carbon can be manufactured from graphite & other form of carbon, coal etc. Carbon brushes are often made of graphite is heat treated to increase the size of crystal.

The important applications of carbon materials as an electrical materials are electrodes for electric arc furnaces and battery, carbon resistances; non-wire resistors & other components of telecommunication.

The most important application of Carbon material is in Commutator and slip-ring brushes (Carbon brush).

Though electrical conductivity of Carbon is less than that of metal, it is used to conduct current for special applications like contact brushes due to its following Advantages over metals:

1. Negative temperature Coefficient of ~~Temperature~~ ^{Res}

With increasing temp^r, conductivity does not decrease like metal but increases.

2. High melting point: It has high melting point about 3300°C like graphite.

3. Low density: It is lighter in weight.

4. Non-weldability: At high ^{temp^r}, it does not join with the contact surface.

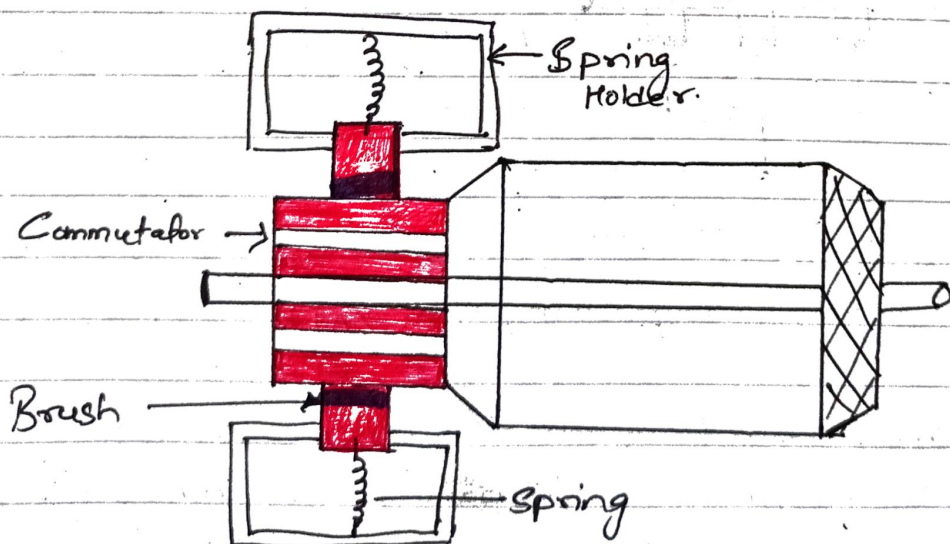
5. Self-lubrication Capabilities: Graphite has a self-lubricating capability which reduces wear and tear due to rubbing.

6. Low-hardness: If brush is made by hard-metal, commutator surface will suffer excessive wear & tear with hard contact.

Product of Carbon.

1. Carbon Brushes: Electrical brushes and brush materials are used in conjunction with slip-rings, commutators or other contact surfaces to maintain an electrical connection in rotary & linear-sliding contact applications. Carbon and graphite brushes are kept in contact with commutator & slip rings which causes rubbing & resulting high temperature.

Brushes used in Commutator: The commutator is a device that functions as rectifier. It converts the A.C. induced in the armature coil of generator into unidirectional current. Brushes are held in a fixed position on commutator by means of a brush holder that is electrically insulated from it as shown in fig (a) below.



Fig(a): DC generator

Spring is used in the brush holder to maintain a contact pressure between the brush and the commutator. The brush pressure should be just right. If the pressure is low, the contact is poor which results in excessive sparking with commutator. On other hand, too high pressure results in excessive wear and tear of brush and overheating of the commutator through friction.

Brush Used in Slip-ring:

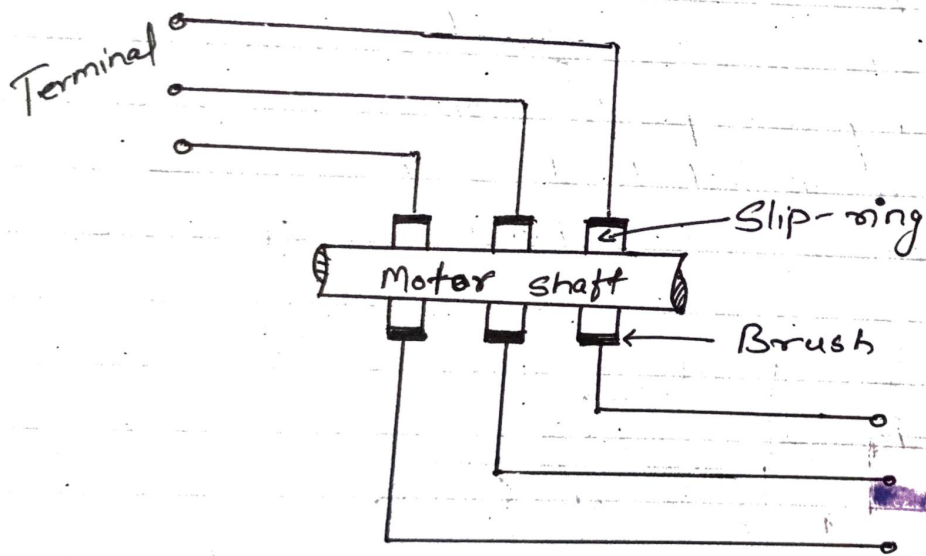


Fig (6): Slip-ring of I/M

Slip-rings are mounted on the motor shaft with brushes resting on them. The brushes are connected to the variable resistor as shown.

In fig (b). The purpose of Slip-ring is to provide a means for connecting external resistor in the rotor circuit and purpose of brush is to make a contact between rotating Slip-ring & static external resistor. The external resistor is used to increase the starting torque.

1.14 Forms of Non-Ferrous Metal:

1. Gun Metal: It is an alloy of Copper, tin and Zinc. It usually contains 88% Copper, 10% tin and 2% Zinc.

This metal is very strong and resistant to corrosion by water and atmosphere. It is extensively used for casting boiler fittings, bushes, bearing etc.

↳ Cylindrical Metal lining used to reduce friction

Lead :→ It is a bluish grey metal having specific gravity 11.36 and melting point 326°C . It is soft metal. It can be cut with knife. It is used for making solders, water pipes, a coating for electrical cables. A lead base alloy contains 83% lead, 15% antimony, 15% tin and 0.5% Copper.

Tin: It is bright shining white metal.

It is soft malleable and ductile. It can be rolled into very thin sheets. It is used for making fine solder, as a protective coating for iron and steel sheets. A tin based alloy contains 88% tin, 8% antimony & 4% copper called babbitt metal (reduce friction if used.)

Zinc: The most of the die casting are produced from zinc base alloys. The composition of two standard die casting zinc alloys are as follows:→

① Aluminium 4.1%, Copper 0.1%, magnesium 0.04% and the remainder is zinc.

② Aluminium 4.1%, Copper 1%, magnesium 0.04% and the remainder is zinc.

Nickel:

The nickel based alloys are widely used in engineering industry on account of their high mechanical strength, anti-corrosion properties (resistance) etc.

Monel metal, Inconel, nichrome are the most important nickel base alloys.

Chromium: When alloyed with steel, it makes steel tougher. It also increases the critical range of temperature.

V.V.I

1.11 Corrosion:

Corrosion is a gradual chemical or, electrochemical attack on a metal by its surrounding such that the metal is converted into oxide, salt or some other compound (Rust). There is various media for corrosion of ferrous metal such as air, industrial atmosphere, soil, acids, bases and salt solutions.

The metal may be corroded as a result of electromechanical or chemical reactions between metal surface and the environment.

OR

The term Corrosion is defined as an act or process of gradual wearing away of a metal due to chemical or electrochemical reaction by its surrounding, such that metal is converted into an oxide, salt or some other compound. Rust is the result of such process. In other words the Corrosion indicates the deterioration and loss of material due to chemical attack.

V.V.I

⊗ Causes of Corrosion:

Following are the factors which are responsible for causing Corrosion:→

- 1.) Unequal distribution of oxygen over the Steel Surface.
- 2.) Due to the presence of Salts.
- 3.) Poor workmanship.
- 4.) Due to inadequate design procedure.
- 5.) Chemical nature of metal.

⊗ Effects of Corrosion:

- 1.) One important effect of corrosion is the formation of crack and these usually progress most rapidly where shearing stresses are greater and where slipp. slipping occurs due to loss of bond.
- 2.) Mechanical Strength is reduced and section ultimately fails if extensive corrosion occurs.
- 3.) Plant system collapse eg: Truss, beam components, tools etc.

⊗ Methods of Prevention of Corrosion of ferrous Metal:

Following are the methods which are usually adopted for the prevention of corrosion of ferrous metal are:→

- 1.) Electroplating:

2. Galvanizing
3. Painting
4. Metal Spraying
5. Tin plating and Terne plating.
6. Coal tanning.
7. Enamelling
8. Parkening
9. Embedding in Cement Concrete.
10. Sherardising.

Description:

1) Electroplating:

In this method, a thin layer of chromium, cadmium, copper or nickel is laid on the surface of ferrous metal with the help of electric current by employing the principle of electrolysis. The surface to be deposited is made by the anode. When the electric current passes through a solution between two electrodes, the solution breaks into ions which deposit on the cathode and the iron is thus electroplated. The surface so formed is smooth and the process produces very bright shining surfaces.

2.) Galvanising: It is the process of zinc plating with thin layer on ferrous metal in order to protect against Corrosion. In this process the ferrous metal is cleaned by removing scales. The surface is then treated with dilute solution of HCl and after washing it is dipped into a bath of molten zinc. The thin layer of zinc grants protect against Corrosion.

3.) Painting: In this method, the surface of ferrous metal is covered with a thin layer of suitable paint. This is the most common method of protecting metal surface from Corrosion.

4.) Metal Spray: In this method, the ferrous metal is covered with a spray of vaporized aluminium, lead, tin or zinc with the help of equipment include a pistol, a bundle of wires of coating metal, compressed air, oxygen and a suitable fuel gas. An oxy-hydrogen flame is produced inside the nozzle of pistol and it results in the melting of wire of coating metal. This molten metal is forced by the compressed air and it is

deposited on the iron surface under high pressure at ordinary temperature.

3. Enamelling: In this method, the surface of the iron is enamelled i.e. provided by a smooth brilliant surface by melting a suitable flux on it. For this purpose the iron piece is cleaned properly and flux on the surface is melted by placing it in a muffle furnace. The first layer consists of borax with cobalt or, nickel oxide and a small quantity of limestone. It is then coated with a second layer of more fusible glaze to give the desired colour to the surface. This method is used for ornamental iron works, sign boards and domestic applications.

1.15 Chemical / Corrosion characteristics of
Some commonly used non-ferrous metal:
Zinc, tin, lead, Nickel

(*) Aluminium: Aluminium in pure form is not affected by pure water but corroded by water containing salt if some impurities are present in the metal.

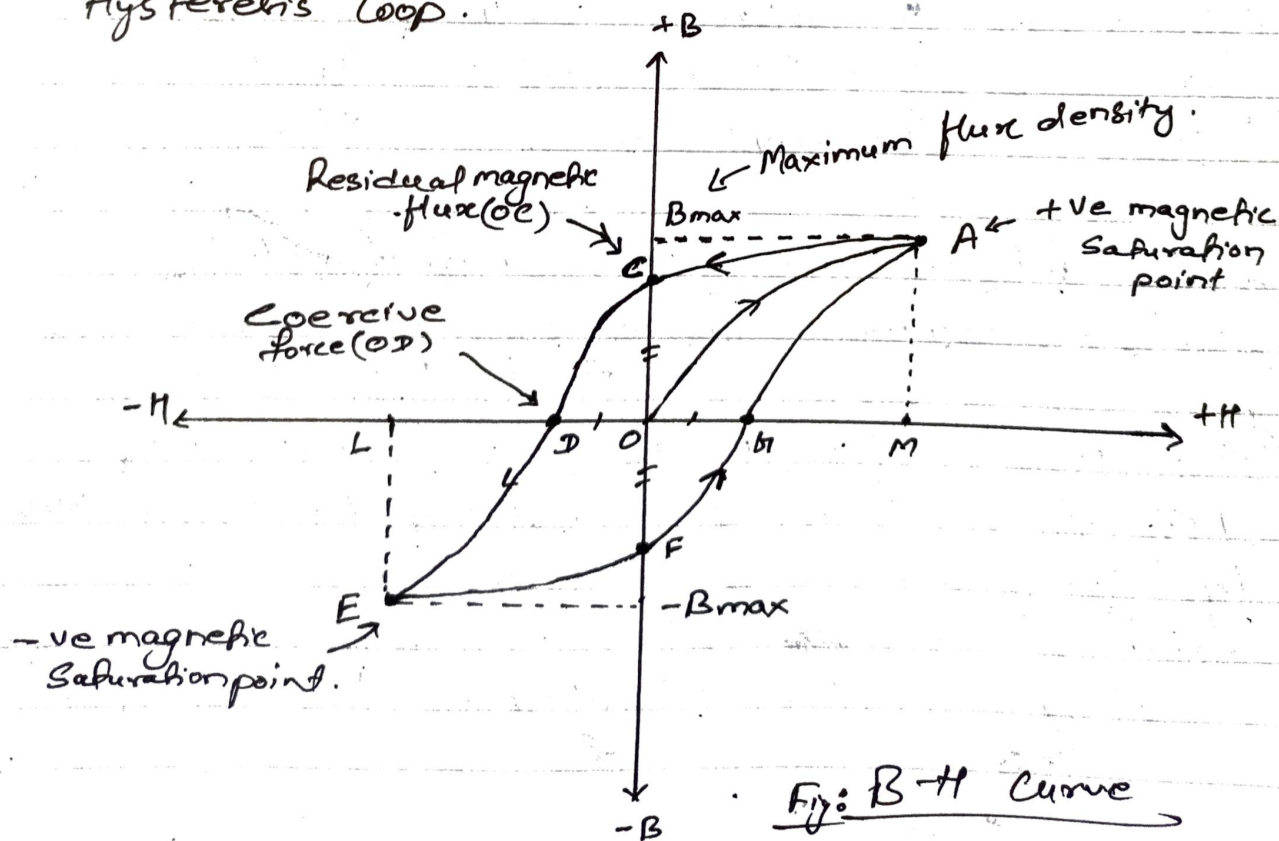


⑧ Copper : Copper is not affected by dry air at ordinary temperature. But when exposed to air and moisture it is covered by green coating is due to the $\text{CuCl}_2 \cdot 3\text{Cu}(\text{OH})_2$ [atacamite]. These compounds are formed from the hydrogen sulphide or, hydrochloric acid present in the atmosphere.

V.V.9.

1.3 B-H curve (Hysteresis loop or curve)

The curve which shows the relationship between the magnetizing force 'H' & flux density 'B' is known as B-H curve or Hysteresis loop.



In above figure ACDEFBA B-H curve is shown.

Whenever an unmagnetized bar of iron AB is placed within the field of Solenoid, the field ' H ' ($\frac{NI}{L}$) is produced by the Solenoid & it depends on increasing or decreasing current through it.

When ' H ' be increased slowly from zero to certain maximum value & return back to negative value, the corresponding value of flux density ' B ' be noted. If we plot the reaction between B & H , a closed loop ACDEFBA is obtained as shown in figure and is known as hysteresis loop.

→ As shown in figure OM = H shows that material becomes magnetically saturated & maximum flux density (B_{max}) is obtained.

→ When the value of H is zero, the value of B is equal to OC which is called the residual flux density (B_r)

→ The value of B for -ve H = OD is zero. So this value of H is known as Coercive force.

→ By further increasing value of H in reversal direction the material becomes again at state of negative magnetic saturation at point E.

1.6 Hysteresis Loss:

On application of magnetic field, domains are aligned in the direction of field. When the direction of field is reversed, the domains swing around ~~and~~ align themselves in the opposite direction. In this process, there is a loss of power, which is called hysteresis loss. If the frequency of the applied field is 'F' then hysteresis loss is

$$P_h = V_{\text{core}} \cdot A_h \cdot F \quad \text{in watt}$$

where,

V_{core} = Volume of the core

A_h = Area of the B-H loop

F = Frequency of the applied field.

Silicon is added in the steel used in core to minimize this loss.

⊗ Eddy Current loss:

The core material of electrical machine (transformer) is made by conducting material so the individual shells are also linked by some amount of the magnetic flux & a local emf is generated in each shell. This local induced emf ~~is~~ flow through the individual shell. Since these current

do not flow in any clear path, they are called eddy current. The power loss due to eddy current is called eddy current loss.

$$\text{i.e. } P_e = \frac{1.645}{\rho} V_{\text{core}} t^2 F^2 B_m^2 \text{ in watt.}$$

Where,

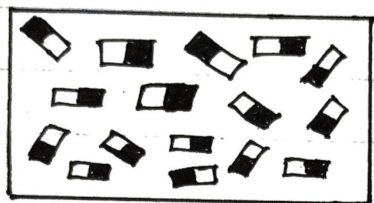
B_m = maximum flux density,
 ρ = resistivity of core material
 t = Thickness of core.

From the above expression, it is clear that the eddy current loss is inversely proportional to the resistivity of the core material. Addition of Silicon upto 4% in steel increases the resistivity & hence decreases eddy current loss.

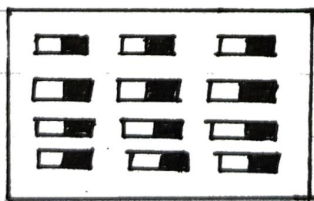
$$\downarrow P_e \propto \frac{1}{\rho_m}$$

1.10 Domain Structure :

Molecules of all substances are inherently magnets in themselves, each having a N-pole & S-pole. In an unmagnetized state it is supposed that these small molecular magnets lie in all sorts of haphazard manner forming more or less closed loop as shown in fig below.

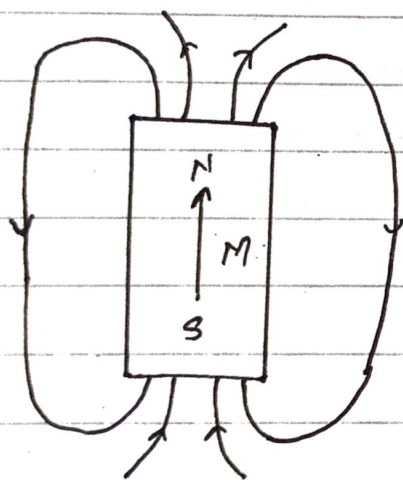


When such an iron bar is placed in a magnetic field then these molecular magnets start turning round their axis & orientate themselves more or less along straight lines parallel to the direction of magnetising force. This linear arrangement of molecular magnet results in N-polarity at one end of the bar & S-polarity at other end of bar.

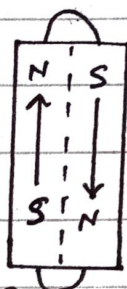


A magnetic domain is a region of the crystal in which all the spin magnetic moments are aligned to produce a magnet in one direction.

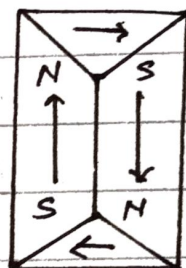
The external magnetic field lines are produced and there is now less potential energy stored in the magnetic field. There are only field lines at the end. The boundary between two domains is called domain wall or Bloch wall, where the magnetization change from one direction to the opposite. The creation of magnetic domain continues until the potential energy reduction increases and additional domain is same as the increase in additional wall.



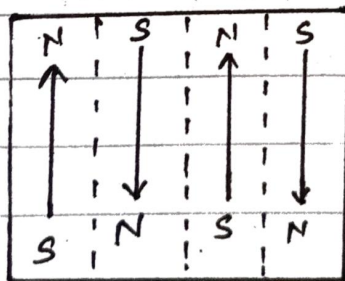
(a) Magnetized bar.



(b) Formation of two domains with opposite magnetization



(c) Domains of closure fitting eliminating field lines.



(d) Specimen with several domains and closure domains.

1.5 Forms of Steel:

The following are the different form of steel:

1) According to the Carbon Content:

- a) Plain carbon steel.
- b) Mild carbon steel.
- c) Medium carbon steel.
- d) High carbon steel.

2) Alloy Steels:

- | | |
|------------------------|------------------------------|
| a) Nickel steel | f) Manganese steel |
| b) chromium steel | g) Tungsten |
| c) Silicon steel | h) Silicon Manganese steel |
| d) Nickel chrome steel | i) Chrome vanadium steel |
| e) Vanadium steel | j) Manganese - Nickel steel. |

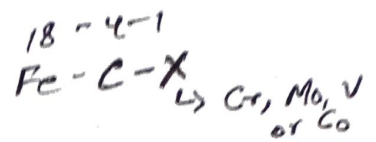
3) High strength low alloy steels.

4) Stainless Steel:

- a) Austentic stainless steel
- b) Martenstic " "
- c) Ferritic " "

5) Tool Steel:

- a) Cold work tool steels
- b) Shock resisting tool steels.
- c) Hot work tool steels.



18% - W as H.H. 18%
 4% - Cr, ^{high strength}
 1% - V.

d.) Plastic mold tool steels.

e.) Special purpose tool steels.

f.) High speed tool steel:

(i) 18-4-1 high speed steel.

(ii) Molybdenum high speed steel.

(iii) Super high speed steel.

(iv) Vanadium high speed steel.

1.) Plain Carbon Steel: Plain carbon steels are classified according to their carbon content as follows:

(i) Dead mild steel.

(ii) Mild low carbon steel.

(iii) Medium carbon steel.

(iv) High carbon steel.

i.) Dead Mild Steel:

% Carbon	BHN	Tensile Strength (MPa)	Yield Strength (MPa)	% elongation	Reduction in area.
0.05 to 0.15	100-110	390	260	40	60

Applications:

Chains, stampings, rivets, nails, pipes, tin plates, automobile body parts.

BHN $\rightarrow$ Brinell
 hardness number.

quenched
→ Steel hardened
by immersing it in
water or oil to cool it.

(ii) Mild (low) Carbon Steel:

- It contains carbon 0.15 to 0.3%.
- It is tough and more elastic than wrought iron.
- It can be easily forged & welded.
- It is malleable and ductile.
- It absorbs ~~see~~ shocks.
- Its tensile strength is better than cast iron and wrought iron but compressive strength is better than wrought iron & less than cast iron.
- Its melting point is 1400°C .

Applications:

- 1) It is used in structure steels beams, screws, bars, rods, plate, angles & channel etc.
- 2) It is also used in machine & structure work like gears, shaft etc.

(iii) Medium Carbon Steel:

- It contains carbon from 0.3 to 0.8%.
- Medium Carbon Steel in the quenched and tempered condition provide good strength & quality.

Applications:

- 1) Medium Carbon Steel having Carbon Content

0.3 to 0.45 is used for ~~Axis~~ ^{Axis} ~~and~~, Special duty shafts, Connecting rods, turbine rotor etc

2.) Medium Carbon steel having Carbon content 0.45 to 0.60% is used for railways coach axis, Crank pins, crank shafts etc.

(v) High Carbon Steel:

→ It contains Carbon percentage from 0.8 to 1.5%.

→ Due to higher hardness, they bear high resistance.

→ It loses its hardness at temperature from 200°C to 250°C

→ These steels are easy to forge and simple to harden.

Applications:

1) When Carbon percentage is from 0.80 to 0.90 it is used for Circular Saws, punches & dies.

2) When Carbon percentage is from 0.90 to 1.20% they are used for Springs, balls, pins, tap tools etc.

1.7 Magnetic dipole moment:

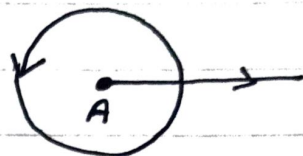
A current carrying loop of area A , the current passing through the loop is I and if the magnetic field produced by the current is uniform throughout the area then, magnetic dipole moment (M) may be represented as:

$$M = IA$$

The unit of M is Ampere Meter^2 (Am^2). In case of a coil having N turns, the magnitude of dipole moment.

$$M = NIA$$

When a magnetic dipole is placed in a magnetic field, it experiences a torque that tries to rotate the magnetic moment to its axis with the magnetic field.



1.8 Magnetising field or, Magnetic field intensity (B):

When a medium is inserted within the solenoid as shown in fig: 1, the magnetic field inside the solenoid changes from B_0 to B and B is given by:

$$\begin{aligned} B &= \mu_0 (I' + I_m) \\ &= \mu_0 I' + \mu_0 I_m \\ &= B_0 + \mu_0 M \quad \text{--- (1)} \end{aligned}$$

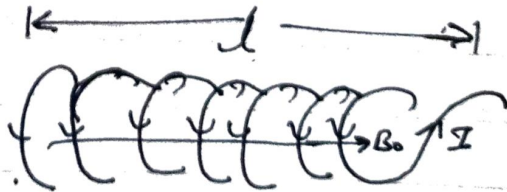


Fig: 9

where, B_0 , B & M all are vector quantities.

The field inside the magnetized material is the sum of the applied field B_0 & a contribution from the magnetization M of the material.

The magnetising field is defined as:

$$H = \frac{1}{\mu_0} (B - M)$$

$$= \frac{1}{\mu_0} B_0 \quad \text{--- (11)} \quad \left[\because \text{Putting the value of } B \text{ from (1)} \right. \\ \left. \& \mu_0 - 1 \rightarrow 0 \right]$$

⊗ Magnetization Vector:

It is defined as the magnetic dipole moment per unit volume.

Total magnetic moment of the cylinder is : $MV = MAL$

where, $V = \text{Volume}$

$A = \text{Area}$

$L = \text{Length}$

If I_m is the magnetization current on the surface per unit length, then the total circulating current is $I_m L$ and total magnetic moment by definition is as:

Total magnetic Moment = Total current $\times$ Area

$$\Rightarrow MAL = I_m AL$$

$$\Rightarrow \boxed{M = I_m}$$

← continue.

The magnetic field inside the solenoid with the free space inside it B_0 is given by:

$$B_0 = \mu_0 n I = \mu_0 I'$$

Where,

I = Current through solenoid

μ_0 = Absolute permeability of free space = $4\pi \times 10^{-7} \text{ H/m}$ (Henry/meter)

I' = Current per unit length

n = no. of turn per unit length

nI = Total current through solenoid.

$$H = \frac{I}{\mu_0} (B - M)$$

$$\therefore \boxed{H = \frac{B_0}{\mu_0}}$$

V.V.9

1.9

Magnetic Permeability & Susceptibility:

The magnetic permeability of the ~~matter~~ medium at any point is defined as the magnetic field (B) per unit magnetizing field (H).

$$\mu = \frac{B}{H} \quad \text{--- (1)}$$

μ represent to what extent a medium is permeable by a magnetic field.

Relative permeability of the material is defined as the fractional increase

$$\mu_r = \frac{\mu}{\mu_0} \quad \mu_r \mu_0 = \frac{B}{H} = \mu$$

In the field (B) w.r.t. the field in free space (B_0) when a material medium is introduced.

$$\mu_r = \frac{B}{B_0} = \frac{B}{\mu_0 H} \quad \text{--- (II)}$$

From eqs (I) & (II), we will get

$$\mu = \mu_0 \mu_r \quad \text{--- (III)}$$

Where,

μ = absolute permeability of the medium

μ_r = relative " " " "

μ_0 = absolute " " free space.

The magnetization M produced in the material depends on the net magnetic field B . It should be natural to relate magnetization M to magnetic field B . Magnetization M is also related to magnetizing field H . i.e.

$$M = \chi_m \cdot H \quad \text{--- (IV)} \quad \chi_m$$

Where, χ_m is magnetic susceptibility and is defined as the ratio of magnetization M to the magnetic field intensity H .

$$\chi_m = \frac{M}{H}$$

The relationship given in eqn (IV) is obeyed by all materials.

P.T.O

As we know,

$$B = B_0 + \mu_0 M$$

$$\text{or, } B = \mu_0 H + \mu_0 M$$

$$\text{or, } B = \mu_0 H + \mu_0 \chi_m H$$

$$\text{or, } B = \mu_0 H (1 + \chi_m)$$

$$\text{or, } B = \mu_0 H \mu_r$$

$$\left[\because \mu_r = 1 + \chi_m \right]$$

$$\text{or } \boxed{B = \mu_0 \mu_r H}$$

Unit: 3 DIELECTRIC MATERIALS

Imp

3.1 Definition of Dielectric:

Those materials in which the electrical conduction cannot occur are known as insulating materials. Those materials are also known as dielectric materials. They are electrically insulating in nature. The band gap between valence band and conduction band is more than 3 eV, so an electron from valence band cannot move to conduction band easily.

The dielectric materials separate two electrical conductors without any passage of current. Using this property, dielectric are used in capacitor. In the simplest situation, all dielectric is an insulator, but all insulators are not dielectrics.

* Macroscopic approach:

The relationship between the electric flux density at a point in a material and electric field strength is given by:

$$D = \epsilon E = \epsilon \frac{V}{d} \quad \text{--- (1)}$$

E = Electric field strength, Vm^{-1}

$\epsilon = \epsilon_0 = 8.854 \times 10^{-12} Fm^{-1}$ for free space

$\epsilon = \epsilon_0 \epsilon_r$ for other material where

ϵ_r is the relative permittivity of the material.

When a voltage V is applied across the parallel plate capacitor, as shown in figure (a) below charges $+Q_0$ to $-Q_0$ will be induced on the surface of these plates based on electrostatic induction.

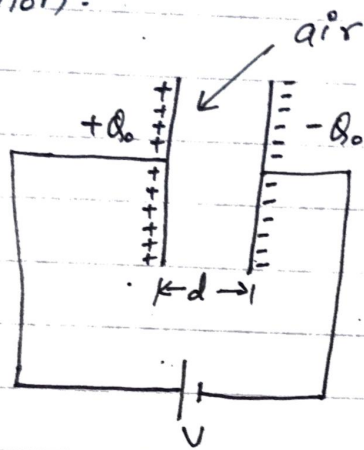


Fig (a)

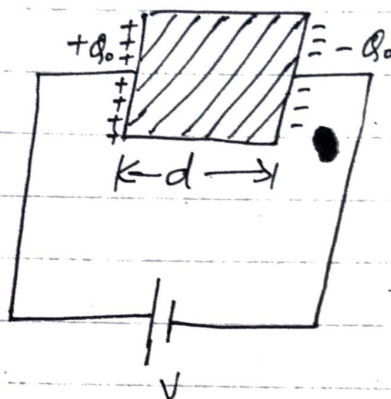


Fig (b)

The capacitance of the parallel plate capacitor is given by:

$$C_0 = \frac{Q_0}{V_0} \quad \text{--- (i)}$$

When a dielectric material is inserted between these plates then, the charges on the surface of the plates get increased due to the appearance of the charge on the surface of the dielectric near to the capacitor plates.

In vacuum the electric flux density is numerically equal to the surface charge

$$\epsilon_0 = Q_0 = \epsilon_0 \frac{V}{d} \quad \text{--- (ii)}$$

Where,

d is the separation between the plates.

Similarly, when there is a dielectric medium inserted between the plates, the above relationship becomes,

$$\epsilon = Q = \epsilon_0 \epsilon_r \frac{V}{d} \quad \text{--- (IV)}$$

The relative permittivity can be defined as increase in charge stored on the capacitor plates due to insertion of the medium compared to the charge without medium.

$$\epsilon_r = \frac{Q}{Q_0} = \frac{C}{C_0} \quad \text{--- (V)}$$

Increase in charge density when dielectric medium is inserted, compared with that without dielectric is called polarization.

$$\text{i.e. } P = \sigma - \sigma_0 = Q - Q_0 = \epsilon_0 \epsilon_r \frac{V}{d} - \epsilon_0 \frac{V}{d}$$

$$\Rightarrow \epsilon_0 \frac{V}{d} (\epsilon_r - 1) \quad \text{--- (VI)}$$

$$\Rightarrow P = \epsilon_0 (\epsilon_r - 1) E \quad \text{--- (VII)}$$

$$\Rightarrow \boxed{P = \epsilon_0 \chi E} \quad \text{--- (VIII)}$$

where,

$E = V/d$; electric field strength

$\chi = \epsilon_r - 1$, dielectric susceptibility;

P = Polarization vector of materials.

Polarization (P) can be defined as the induced charge within dielectric per unit area.

$$P = \frac{Q'}{A} \quad \text{--- IX ---}$$

From above relationship we can conclude that, for the value of relative permittivity equal to unity, there will be no polarization ($P=0$). Hence, no additional surface charge on the plate.

v.v.2

④ Electric dipole moment:

Electric dipole moment is simply the separation between a +ve and -ve charge of equal magnitude. If Q is the magnitude of charge and are separated by a distance of d from -ve charge to +ve charge,

the electric dipole moment is defined as the product of charge and distance. The dipole moment is denoted by ' M ' & is a vector quantity that is directed from -ve to +ve charge as shown in fig (a.)

$$M = Q \times d$$

$$| \leftarrow d \rightarrow |$$

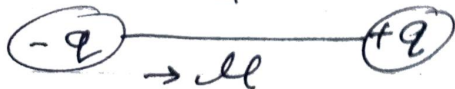


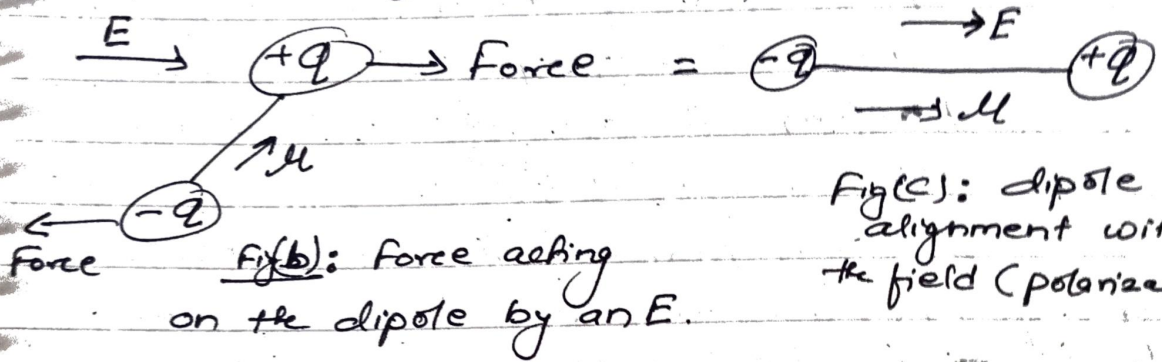
Fig (a)

⊕ Dielectric Constant, Note prep.

Q.9

⊗ Polarization:

If an electric field E is applied on dipole then, a force or torque will act on the dipole to align it in the direction of E & finally the dipole will align. This process of dipole alignment is termed as polarization.



A parallel plate capacitor, where two thin plates is connected with +ve and -ve end of the applied field as shown in figure.

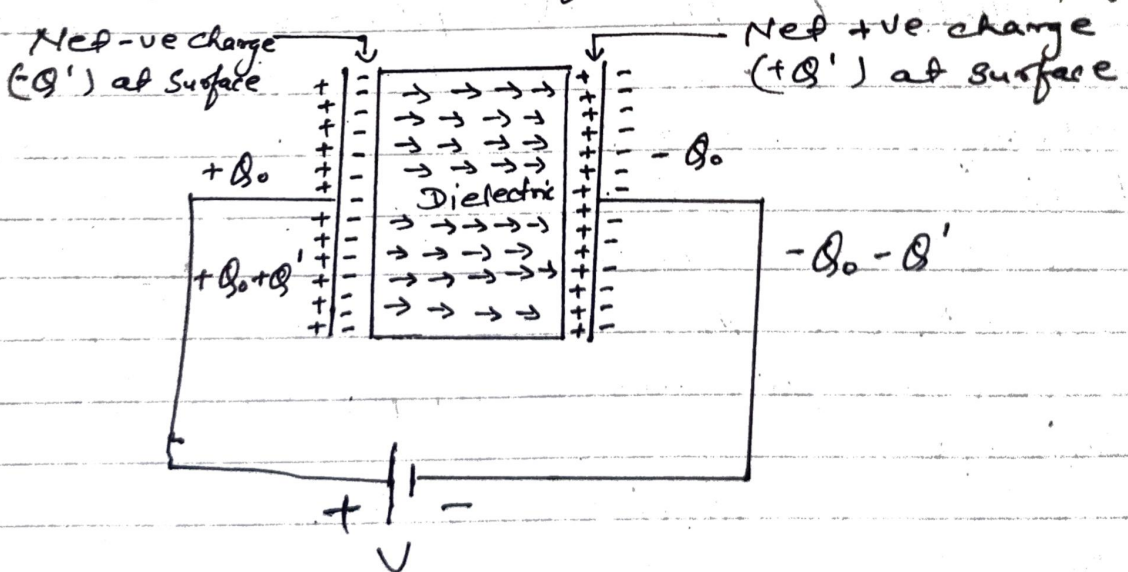


Fig: Schematic representation of Capacitor Polarization

A dielectric material is inserted between the parallel plates. The symbol $\rightarrow$ indicates the atomic or molecular dipole moment & its direction. In response to the applied field, the dipoles will align parallel to the field. At the top surface of the dielectric, there appears a net -ve charge ($-Q'$) amount & that in bottom surface of the material the net +ve charge ($+Q'$).

If each plate & the adjustment surface of the dielectric are considered as the single, then for top plate, Q' amount of charge is nullified (added) from $+Q_0$, charge due to the result of $-Q'$.

Electrons flow from the +ve plate to the -ve plate, by external voltage source such that the proper voltage is re-established. The magnitude of the stored charge in each plate $Q_0 + Q'$ have been increased by an amount Q' . This is the reason why dielectrics are used in parallel plate capacitor.

Quantitatively polarization can be defined as the total displacement per unit volume.

$$\therefore \text{Polarization (P)} = \frac{\text{Dipole moment}}{\text{Volume}}$$

The dipole moment per unit volume of the solid is the same of all the individual dipole moments within that volume and is called the polarization, P of the solid.

$$P = \frac{Zqd}{V}$$

Ans.

* Electronic Polarization:

This type of polarization is observed almost in all materials. An atom is made by +vely charged nucleus and -vely charged electrons revolving around the nucleus. In the absence of external field, the centre of -ve charge and the centre of the +ve charge coincides, so they cancel each other and atoms as a whole possess no dipole moment.

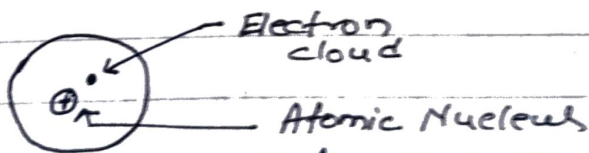


Fig (a) A neutral atom.
 $P = 0$

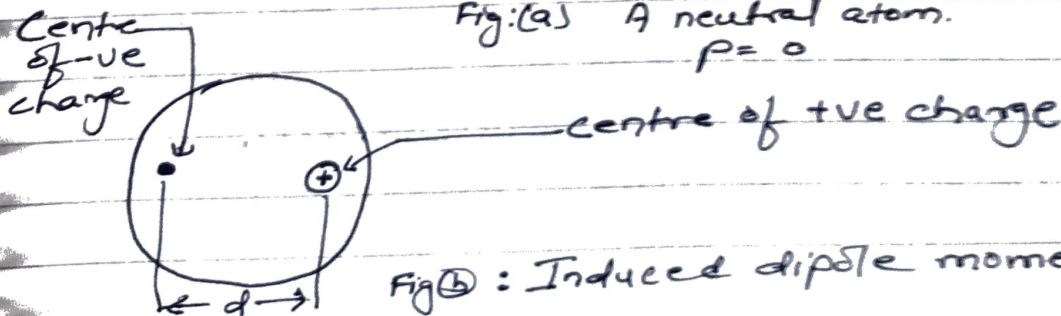


Fig (b) : Induced dipole moment.

In an atom when there is no applied field, the centre of mass of atom & the charge centre coincide with each other. So, accrd to the defⁿ of electric dipole moment, the dipole moment with the atom is zero. But when external field is applied, the atomic centre of mass doesn't change as the mass of atom is mostly due to the contribution from the nucleus. In the other hand, the charge centre for +ve charge is unchanged, the -ve charge centre will be shifted in the dirⁿ of opposite to the dirⁿ of applied field. The separation of charge centres means that there is induced ^{electric} dipole moment which is termed as polarization.

The induced dipole moment depends upon the electric field causing it. It is related to the applied field as:

$$P_{ind} = \alpha E \quad \text{--- (1)}$$

Where,

α = Polarization of the atom.

Since, the polarization of a neutral atom involves the displacement of electrons, α is called electronic polarizability or, Coefficient of electronic polarization.

Electronic Polarizability can be calculated by using the following expression.

$$M_e \omega_0^2 \alpha = \frac{Z e^2}{4 \pi \epsilon_0 r^2} \quad \text{--- (2)}$$

$$\alpha_e = \frac{Z e^2}{M_e \omega_0^2}$$

Where,

Z = atomic number

ω_0 = oscillation frequency of centre of mass of the

M_e = mass of electron &

e = charge of electron.

Imp

(*) Ionic Polarization: In polyatomic molecules

where bonding is ionic in nature, an applied field E will not tend to shift the +ve ion relative to the -ve ions.

As a result an electric dipole is induced.

The polarization due to this dipole is called the ionic ~~polar~~ polarization. These molecules

can be characterized by an ionic polarizability (α) which is determined in the same way as α_e .

Ionic polarizability is also independent of temp^r.

Electric Field (E)
→

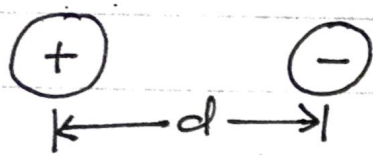


Fig (a)

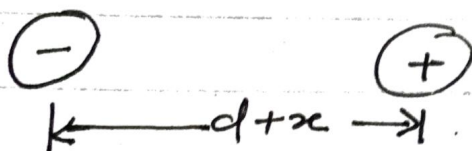


Fig (b).

Fig: Ionic Model

- ④ in the absence of E; and
- ⑥ The shift of the -ve ion relative to the +ve resulting dipole moment. The ion is displaced by x from initial separation d .

In this case dipole moment is due to the displacement x between the two ions. Electronic polarization is also present in this material. So, the material has electronic & ionic contribution in total polarization, so it ~~is~~ can be written as:

$$P = P_e + P_i \\ = N (\alpha_e + \alpha_i) E$$

Where,

N is the number of atoms in the system.

⊗ Dielectric losses:

Dielectric losses are due to the absorption of energy by the material from the field, when an altering field is applied on a dielectric material, the produced dipoles tend to align along the dirⁿ of applied field. For that a molecular re-arrangement of charged particles for each field reversal is needed.

The material has some internal resistance during this re-arrangement. The energy absorbed from the applied field is used to overcome the resistance & then the energy is dissipated in the atmosphere as heat. This absorbed energy is the dielectric loss under alternating field. The dielectric loss should be proportional to the frequency of the applied field.

The energy losses in a dielectric are due to :

- Ⓐ Ionization ;
- Ⓑ Leakage current ;
- Ⓒ Polarization ; &
- Ⓓ Structural inhomogeneity.

* Effect of Frequency:

We know that dielectric loss is proportional to the frequency of the applied field. At low frequency the dipole can respond with the change in applied field; so dipolar polarizability is maximum in this region. In high frequency range the dipoles cannot respond to the change in applied field. The high frequency field cannot polarize the material, means the orientational polarizability is zero.

* Effect of Temperature:

In most of the cases; increased temperature indicates towards increased thermal agitation of molecules, which always hinders the orientation of dipoles within the material. So, the dielectric constant is smaller at high temp^r. compared to that at lower temp^r. The dielectric strength will be lower at higher temperature than at lower one.

V.V.I

* Dielectric Breakdown:

The dielectric materials are widely used as insulating media between conductors at different voltages to prevent ionization of

air & current flashover between conductors. The voltages across conductors and hence within the dielectric cannot be increased without limit. A voltage will be reached when current starts flowing through the dielectric, which is called dielectric breakdown.

In gases & liquid, the breakdown is not permanent but in solid breakdown can be permanently damage. The maximum electric field that can be applied to the insulating material without causing dielectric breakdown is called dielectric strength of the materials.

V.V.I

⑦ Dielectric breakdown in gases:

The breakdown in gases depends upon pressure; higher pressure means greater concentration of molecule & the reduced separation between molecules, hence the shorter free path of free electrons. This means free electrons should be accelerated by larger energies to impact ionize the neutral gas molecule. So, dielectric strength is greater at higher pressure.

avalanche: Sudden appearance of overwhelming no. of things

When local region is exhibiting discharge so, that the discharge does not directly connect two electrodes, it is said a partial discharge.

For a high voltage cylindrical conductor above a grounded electrode, the electric field is highest near the surface of the conductor facing ground. This field starts discharge locally because the field is sufficiently strong to continue the electron avalanche. But away from the conductor due to weak field, there will be no electron avalanche. Such local discharge voids and cracks within the solid dielectric material & discontinuities at dielectric electrode interface can also lead to partial discharge. Since the electric field in these voids & cracks are stronger than in dielectric material, these void & cracks erode the surrounding region of the dielectric both physically & chemically, which can lead to major breakdown, if not controlled in proper time.

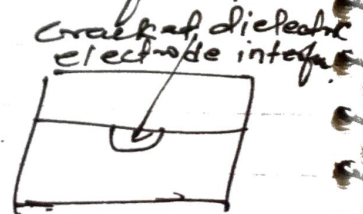
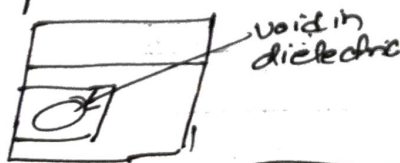
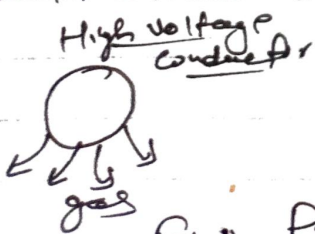


Fig: Partial discharge in gases.

J.V.I

(*) Dielectric breakdown in liquids :

The process that leads to breakdown in liquid dielectric is not as clear that in gases. In impure liquid with small particles in suspension, it is believed that these impurities joined end to end to form a conducting bridge between electrodes thereby give rise to breakdown. Sometimes, discharge starts as partial discharge in gas bubbles entrapped in liquids.

Moisture absorption & gas absorption deteriorates the dielectric strength of liquids. In oil in a long run, oxidation produces acidic products & some parts may become more conducting by this and can give rise to discharge electron emission from electrodes at high field also can initiate discharge in liquids.

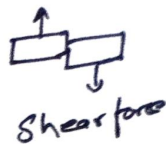
* Dielectric Breakdown In Solid:

There are various mechanism of dielectric breakdown in Solids such as: intrinsic breakdown, thermal breakdown, breaking due to insulation ageing, electromechanical breakdown ^{etc.}

In intrinsic breakdown, which is also called electronic breakdown, an electron in the conduction band of dielectric can be accelerated with large energy to impact ionize atom. The collision of electron with energy more than the band gap energy is capable of ~~existing~~ ^{exciting} electron from valence band to conduction band and then further both the primary and secondary electrons will impact to ionize other atoms there by generating an electron avalanche effect.

If the heat generated in the solid cannot be removed quickly by thermal conduction, the temp^r of dielectric increases & leads to higher electrical conductivity, which will cause more joule heating. Certain local area can become hot spot & if there are many such hot spots in the dielectric there can be permanent conducting channel connecting two electrodes and hence a thermal breakdown of dielectrics.

Mechanical breakdown is the force experienced by dielectrics due to oppositely



Shear force

charged particles plates between which it is placed. The compressive force increases with the increase in voltage. The thickness of the dielectric is reduced which will increase the charge on the electrode as given by $Q = CV = \epsilon_0 \epsilon_r \frac{A}{d}$ which will lead to increase in compressive force & decrease in thickness.

This process will continue till the dielectric deform plastically causing the insulation to breakdown by increase in field. The increase in 'E' & decrease in 'd' produces more joule heat and dielectric loss heat causing more problems for mechanical stability of material. It is possible to reach thermal breakdown due to mechanical deformation. There is a possibility of internal cracks & these cracks develop shear force, which combined with large electric field, can cause crack propagation & eventually mechanical & hence dielectric failures.

* Piezo - electricity :

We know that polarization of dielectric material can be changed by varying the applied field strength. In some material, it can also change by stress and temp^r. If the polarization is changed due to application of stress or vice-versa, then the material is called piezoelectric material. But if the polarization is changed due to temp^r, then the material is called pyroelectric. Some of the common dielectrics which are used practically as piezoelectricity are quartz, Barium Titanate (Ba Ti O_3), TOPAZ, Sugar, bone etc.

These materials are practically important because it permits conversion of mechanical energy into electrical energy and vice-versa. There are two types of effect in piezoelectricity materials :- one is direct effect & another is inverse effect.

Direct Effect

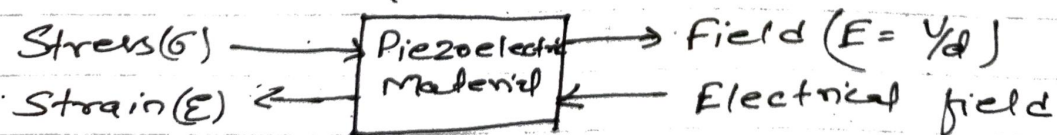
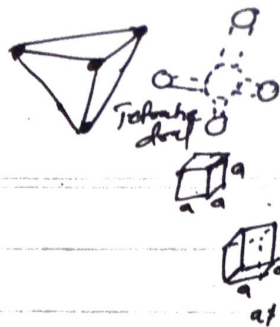


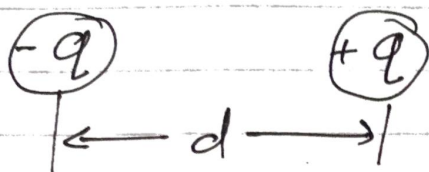
Fig: Schematic representation of field (E) of piezoelectric I/P & O/P

Application:
P. has lighters
Piezo-electric
microphone

Strain gauges.
Loudspeakers.



Inverse Effect



If σ compressive, d decreases &
E developed bet? Crystal $E \propto \sigma$

* Ferro-electricity:

Certain crystal like: Barium titanate (BaTiO_3) which have permanent polarization even in the absence of an applied field are called ferroelectric crystal & the phenomenon is called ferroelectricity. Above 130°C , the crystal structure of BaTiO_3 has a cubic structure & center of mass of +ve & -ve charges coincide & the net polarization is zero. Below 130°C , BaTiO_3 has tetragonal structure & centre of mass of +ve & -ve charges do not coincide so there is polarization 'P' as there is separation bet? +ve & -ve charge center. The temperature above which the ferroelectricity is lost is called Curie temp. ' T_c '.

Below T_c , specimen becomes polarized & above T_c , disorderness of dipole increases which is called pyroelectric effect.

④ Insulating Materials:

Electrical insulating materials are poor conductor of electricity means that these materials strongly oppose electricity. So the electrical insulating materials may be defined as those materials which offer a very large resistance to current flow.

Dielectric materials provide insulation as well as charge storing capacity. When the main function of dielectric is to provide insulation, then dielectric materials are called insulators & when the main function is to store energy then it is called dielectric.

Valence band of these materials is separated from the energy conduction band by a wide energy gap, which is of the order of 3eV or more. This energy gap is so wide that at ordinary temperature the electrons cannot jump from valence band to the conduction band. As a result of this no electrical conduction takes place.

Insulating materials have very large insulation resistance at ordinary temperature. This resistance decreases with the increase in temp.ⁿ

* General properties / characteristic of Insulating materials:

The selection of the insulation system is mainly based on the following properties:

- ① Mechanical properties.
- ② Electrical properties.
- ③ Thermal properties.
- ④ Environmental properties.
- ⑤ Chemical properties.

Except these some other properties like visual properties, ageing, economy & availability are also considered.

① Mechanical Properties:

The main mechanical properties are for fabrication. The important properties are viscosity, porosity, solubility, compressive strength, tensile strength, modulus of elasticity, impact strength, ductility, malleability, machinability etc.

Mechanical strength is required in order to withstand the load in its service life. Application of liquid material depends on viscosity. Machinability, Malleability & ductility is required for processing & fabrication of insulator. Porosity increases the capacity of

Varnish $\rightarrow$ Coating provides a hard, lustrous, transparent finish to surface.

absorbing the moisture which affects other electrical properties, Solubility is required in some particular cases for Varnish.

② Electrical Properties:

The important electrical properties are:

- ① Electrical resistance;
- ② Dielectric Strength
- ③ Dielectric Constant
- ④ Dielectric Losses.

③ Electrical Resistance:

The current carried by the insulating materials may be divided into two parts:

- ① the surface current (I_s) flows through surface &
 - ② if flows through the entire body of the material called the Volume Current (I_v).
- So, electrical resistance of insulating material can be classified into two ways:-

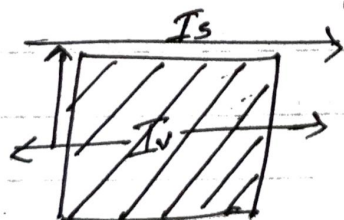


Fig: Schematic representation of two current components.

(i) Surface resistance (R_s):

The resistance offered by the surface to current is called surface resistance.

(ii) Volume resistance (R_v):

The resistance of a material against the current (I_v) when current flows through the entire volume is called the volume resistance. Mathematically, it is represented as:

$$R_v = \rho_v \frac{l}{A}$$

where,

ρ_v = Volume resistivity

l = length of resistance insulator

A = Area of the insulator across current.

(B) Dielectric Strength:

The ~~dielectrical~~ dielectric strength is defined as the breakdown voltage per unit thickness of the material. The dielectric strength is also called dielectric breakdown voltage. So, it is a maximum voltage gradient which an insulating material can withstand.

The breakdown voltage depends on the thickness, so the design of insulation needs to consider the thickness of the material.

2). Dielectric Constant:

Dielectric Constant of dielectric medium is the ratio of absolute permittivity of a dielectric medium to the absolute permittivity of free space

is.
$$\epsilon_r = \frac{\epsilon}{\epsilon_0}$$

df. Dielectric losses:

If the dielectric material is subjected to an alternating field, the material absorbs some electric energy, which is released as heat. This absorbed electric energy is termed as dielectric loss. The dielectric loss increases due to:

- ① Humidity;
- ② Temp^r rise;
- ③ Voltage increases;
- ④ Frequency.

So, dielectric loss is a problem for insulating materials.

3. Thermal Properties:

One of the important properties of insulating material is heat transfer. Poor heat transfer results in the increase of insulation temp^r which affects on mechanical as well as

electrical properties. Temp.^r rise, decrease the mechanical strength & insulation resistance. Very high temp.^r cause mechanical as well as electrical breakdown. The thermal properties are Melting point, Volatility, thermal - Conductivity, coefficient of thermal expansion and heat resistance,

4. Environmental Properties :

It is both chemical effect as well as an effect of fluctuation of surrounding temp.^r. more or less moisture is always present in atmosphere which highly effect on insulating properties. If the insulating material is placed in a humid atmosphere moisture is absorbed by the surface of an insulation and then diffused to the inner portion.

5. Chemical properties:

The insulating materials are affected in the presence of moisture, alkalies, acids, salts, etc. The most important chemical property is chemical inertness, means an insulator in contact with another material, should not ~~react~~ chemically with the material. So at various place plastic has replaced other types of insulating

* Characteristic of a good insulating material
should pass the following characteristic
properties:

- 1) Large insulation resistance.
- 2) It should have high dielectric strength.
- 3) It should have uniform viscosity.
- 4) It should have least thermal expansion.
- 5) It should have fire proofing qualities.
- 6) It should be chemically resistant to oil, moisture, acids etc.
- 7) It should have high mechanical strength.
- 8) It should have high thermal conductivity & thermal strength.
- 9) It should have good surface finish.

* Insulating Materials : Plastics, resin,
porcelain, glass, fiber, glass, Mica,
oil, insulating varnishes, gases (SO_2) :-

* Plastic Materials:

Properties:

- 1) It has good chemical resistance, low coefficient of friction.
- 2) It has high weathering resistance, high

glue used as
lining to
reduce friction
insulator liner

temperature resistance.

3) It is insoluble in water, alcohol & Organic Solvents.

4) It has ~~im~~ high impact, tensile strength over a wide range of temperature.

5) It's dielectric constant & loss depends on frequency.

6) Its cost is low.

7) It is light in weight.

Uses:

1) It is used in power Coaxial cables, telephone cables, TV lead, in wires.

2) It is also used in bushing, handles & jacketing for wires cables, cable sheathing.

3) It is used in connectors, washers, cable clamps, Switch housing.

4) Polyester fiber glass is used to make paper, mat & cloth for electrical application.

~~#~~ Resin:

Properties: These are organic polymers & may be natural or synthetic. The resins have good dielectric & mechanical properties. The dielectric constant of resins varies betⁿ 2 to 4.5 & dielectric strength is quite high.

Uses:

The resins are widely used in engineering industry as dielectric & insulating materials. They are also used as an insulating material in radio, T.V, Power cables etc. They are used as dielectric material in D.C & high frequency capacitors.

#1) Porcelain:

Properties:

- 1) It is a ceramic product made from china clay, quartz & feldspar.
- 2) It is hard, heat & weather resistant insulating materials.
- 3) Resistivity of porcelain at 20°C is $> 10^{11}$ ohm/cm
- 4) The dielectric strength of porcelain is 35 kV/mm
- 5) The dielectric constant of porcelain is 6.

Uses:

It is used in power transmitting & distributing equipment where it is used in support for overhead lines, switch & fuse.

Glass:

Properties:

- 1) The dielectric constant of glass varies from 3.7 to 10.
- 2) The density of glass varies from 2.2 to 6 gm/cm³.
- 3) The volume resistivity varies from 10^{12} to 10^{20} Ω -cm.
- 4) The dielectric loss of glass which is a function of frequency varies from 0.004 to 0.020.
- 5) The dielectric strength of glass varies from 3000 to 5000 kV/cm.

Uses:

- 1) It is used as an insulator because of its low dielectric loss, slow ageing & good mechanical strength.
- 2) It is used as a cover & for internal supports in electric bulbs; electronic valves, Mercury arc switches, X-ray equipment & capacitor & as insulators in telephones.

Fiber glass:

Properties:

- 1) Fiber glass is a glass that has been drawn into fine, flexible fibers or filaments.
- 2) The excellent insulating properties of fibrous glass are due to the large pockets of air betⁿ the fibres.
- 3) Fiber glass have inorganic nature which makes them highly inert.
- 4) High strength to weight ratio.
- 5) It has high resistance to heat.
- 6) It has high operating temp.

Uses:

The major engineering uses are thermal & caustical (heat) insulation & as reinforcements, primarily for plastics.

MICA:

Properties:

- 1) The compressive strength of mica varies from 2000 - 5800 Kg/cm^2 .
or, $() \times 10^5 \text{ N/m}^2$
- 2) The dielectric strength of mica is 1000 KV/mm

3) The resistivity of mica varies from $10^{14} - 10^{15} \Omega \text{cm}$.

4) It is strong, tough & high abrasion resistance.

5) It ~~has~~ ^{has} also hardness & structural stability.

6) It has high thermal resistance.

Uses:

1) It is used where electrical properties are more important like Capacitor, accumulator etc.

2) It is also used in domestic application like iron, hot plates, toasters etc.

Oil:

Properties: The following are the important properties of oil as insulator.

① Dielectric Strength:

It is an important characteristics of oil as an insulating material. If the dielectric strength is low the oil is of poor quality containing water & other impurities.

② Viscosity:

A low viscosity is required for easy flow & also increases the heat transfer rate.

X_{med} oil $\rightarrow$ Alkalene oil.

e) Flash point:

Flash point is the temp^r. at which a mixture of oil vapour & air is ignited by a spark or flame which is brought close to it. The oil must have flash point in order to reduce fire hazard. eg: Transformer oil.

Dielectric strength $\rightarrow 25 - 30 \text{ kV/mm}$
Resistivity at $20^\circ\text{C} \rightarrow 10^{13} - 10^{14} \Omega\text{cm}$
Dielectric Constant $\rightarrow 2.25$

Uses:

The insulating oil are used in Capacitors, transformers, Circuit breaker etc.

Insulating Varnishes:

Properties

- 1) It has high insulating resistance.
- 2) It has very good arc resistance as well as moisture resistance.
- 3) It has also good thermal and mechanical shock resistance.
- 4) The dielectric constant of insulating varnishes varies from 3-4.

- 5) The resistivity of insulating varnish at 20°C varies from $10^3 - 10^4 \Omega\text{-cm}$.
- 6) The dielectric strength of insulating varnish is 4 kV/mm .

Uses: It is mostly used in winding of transformer, motor etc i.e. in magnetic coils means coating of motor coils, armatures, transformer winding.

SF_6 (Sulphur Hexafluoride)

Properties

- 1) It has high dielectric constant compared to other gases.
- 2) Dielectric strength is 79.3 kV cm^{-1}
- 3) It is non-toxic
- 4) It is non-flammable
- 5) It is heaviest known gas [5 times air]
- 6) It can be liquified at approximately 200 PSI.

[$\therefore$ Unit of pressure in kg/s^2]
PSI

$$P = \text{N/m}^2 - \text{S.I (pascal)}$$

$$\text{N/mm}^2 (\text{Kpascal})$$

- 7) It has arc interruption properties.
- 8) Good cooling properties as compared to air or nitrogen.

9) SF_6 is widely used due to its high dielectric strength & good arc interruption properties.

Uses:

It is used in Circuit Breaker, where higher arc interruption is required. and H.I.S.