Chapter-01 28.07.2020 EEM 3rd class

Factors affecting resistivity are

1. Temperature
2. Alloying
3. Mechanical stressing

$R = \rho \frac{L}{a}$

Resistivity $\propto \frac{1}{\text{conductivity}}$

$\rho \propto \frac{1}{\sigma}$

Alloying

By adding some impurities to the pure base metal, its resistivity is increased. When copper (60%) is alloyed with zinc (40%), brass is formed. When metal is alloyed it also acquire high mechanical strength.

The alloy brass will be used for making structural products like rods, shaft, plug points, socket outlets etc.

Mechanical stressing

Resistivity is affected under the influence of different heat treatment process. The fabrication of the conductor from critical to final stage consist of hot working and cold drawing operation. Cold working generally tends to harden the material. So tensile strength is increased and resistivity is also increased. Annealing restore the electrical conductivity of the material.

Classification of conducting materials

→ Low resistivity materials
→ High resistivity materials

Low resistivity materials

These materials are used in house wiring, conductors

for transmission & distribution of electrical power.
for windings of transformer, motor, generators etc.
These materials are having properties like

① Low temp. coefficient-

$$V = IR$$
$$P = I^2R$$

The change in resistance with change in temp. of the material should be low. This is necessary to avoid variation in voltage drop & power loss in the transmission lines.

② Sufficient Mechanical strength-

29.07.2020

The overhead conductors that are used for transmission and distribution of electrical power are subjected to mechanical stress due to wind and their own weight. All the application should have sufficient mechanical strength otherwise they may break.

③ Ductility- conductors should be ductile enough so that they will become capable of being drawn into different shape and size.

④ Solderability- conductors often required to be jointed. That joint should offer minimum contact resistance which is resulted from proper soldering. So while selecting the material this property should be considered.

⑤ Resistance to corrosion- All the conducting material should be such that it is not corroded when used in outside atmosphere.

High resistivity materials

Low conductivity

They are used as resistance element in heating devices, precision measuring instrument, Loading resistance, properties of rheostat, filaments for incandescent lamp.

High resistivity materials

① Low temp. coefficient - All the high resistivity materials should have negligible temp. coefficient otherwise the accuracy of measurement will be reduced.

② High melting point - The conducting materials that are used in electrical heating devices should be able to withstand high temp. for a long time without melting.

③ No tendency for oxidation - The materials should be able to withstand high temp. without any oxidation. otherwise the amount of heat radiation will be reduced.

④ Ductility - High resistivity materials are required in different shape and size. so they should be ductile enough.

⑤ Sufficient mechanical strength - High resistivity materials that are used for different application should have sufficient mechanical strength otherwise they may break during drawing of the wire and subsequent operation.

30.07.2020

Low resistivity materials and their application

Copper

→ It is very widely used as conducting material. Silver is having low resistivity than copper but because of its cost it is not widely used.

→ Copper is reddish in colour and can be available in hard drawn and annealed form.

→ Hard drawn copper is springy and annealed copper is flexible.

→ The resistivity of annealed copper is $1.72 \times 10^{-8}$ and that of hard drawn copper is $1.72 \times 10^{-8}$ Ω-m.

→ Density & melting point of annealed copper is 8.89 and 1084°c. that of hard drawn copper is 8.93 and 1084°c.

→ The application of hard drawn copper are overhead conductors, high voltage application.

→ The application of annealed copper are flexible wire, low voltage power cables, making coils.

→ 10 to 30% of nickel will be added with copper then it is used as contact material.

<u>Silver</u> –

→ It is having good electrical conductivity and resistance to corrosion.

→ To make it hard, 15% of copper is added to it.

→ To make it more hard for to be used in commutator segments an alloy of copper & silver is used.

<u>Gold</u> –

→ It is the best known electrical conductor. It is found in the veins among the rocks and ores of other metal.

→ It is also found in the form of dust in the beds of river.

→ It boils at 1063°c and melts at 2700°c.

→ Density is 19.3 times than that of water.

→ It is ductile and can be easily beaten into transparent sheets as thin as 0.00001 mm.

→ Its good corrosion resistance property makes its useful for to be used as contact material.

## Steel

→ Steel contains iron with a small percentage of carbon added to it. Iron itself is not very strong but when carbon is added it assumes very good mechanical properties.

→ With the addition of a small percentage of carbon tensile strength of steel increases but at the same time its ductility decreases.

→ Steels are classified as
Mild steel containing carbon about 0.25%.
Medium steel containing carbon about 0.45%.
High carbon steel containing carbon about 0.70% and above.

→ Steel is easily corroded when exposed to atmosphere. When a zinc coating is provided on its surface it does not corrode.

## Aluminium

→ Aluminium is widely available in India and is used extensively in the field of electrical engineering.

→ Its resistivity is $2.8 \times 10^{-8}$ Ω-m. Its density is 2.68.

→ Its melting point is 655°C. Like copper it can be easily rolled & drawn hard.

→ It is annealed after it is hard drawn. It can be drawn into thin wires.

→ Aluminium is soft metal but when alloyed with some other material like magnesium, silicon or iron, it acquires higher mechanical strength and can be used for overhead transmission lines.

→ Unlike copper oxide layer, aluminium oxide layer when formed on the surface acts as insulation because aluminium oxide has relatively higher resistivity.

→ Due to insulation property of aluminium oxide formed on the surface, it is difficult to solder aluminium wires. However special flux is now being developed for soldering aluminium wires.

→ Alumenium is quite extensively used for flexible wires, overhead transmission lines, busbar, squirrel cage induction motor rotor bars & in many other application.

## Stranded conductor

→ when single conductor of large crosssection is used, it becomes rigid in construction and is liable to kinks & breaks while handling.

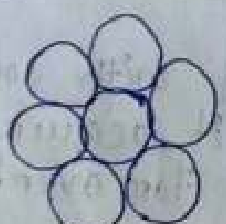
→ To avoid this conductors are made of a no. of thin wires, bunched together called strands.

→ A stranded conductor is made by twisting the wires together to form layers.

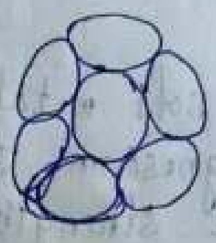
→ A standard stranding consist of 6 wires around 1 wire, then 12 wires around 6, then 18 wires around the 12, then 24 wires around the 18 and so on.

→ Stranded conductors are expressed as 7/2.24, 19/2.50, 37/2.06, 61/2.50

→ Circular stranded conductors are normally used for single phase system. Compacting is carried out by pressing the circular stranded conductors through rollers or dies.



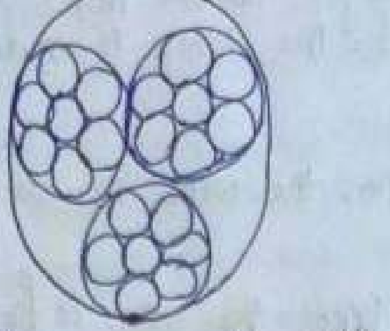
Circular stranded conductor



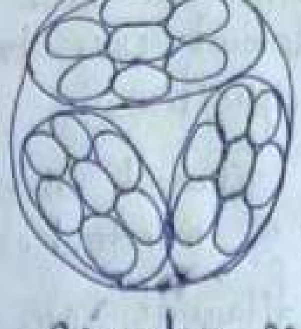
compact circular stranded conductor

→ present day transmission & distribution of electricity is mostly carried by three phase system. This requires three stranded conductors to be individually insulated & put together to make three core cable.

→ Better utilization of space & thus of insulating materials can be made if the circular conductors are made sector shaped.



Three core cable with circular stranded Conductors



Circular conductors made sector shaped

## Bundle conductors

→ The adoption of bundle conductors in extra high tension power transmission enables stranded conductors to be employed and gives an increased current carrying capacity compared with a single conductor of equivalent crossectional area.

→ since the voltage stress at the conductor surface is reduced by using bundled conductors, corona loss is smaller and the line is less liable to cause radio interference.

## High resistivity materials & their application

### Tungsten

→ It is a very hard metal. Resistivity of tungsten is about twice that of aluminium.

→ Its melting point is ~~twice~~ the highest of all the metals. It can be drawn into very thin wires required for making filaments.

→ Tungsten is very commonly used in incandesent lamps, as heater in electron tubes etc.

→ In the atmosphere of inert gas or in vaccume, tungsten can reliably work at temperature like 200°C and even higher.

→ It oxidises very quickly in the presence of oxygen even at temperature of few hundred degree centigrade.

→ when tungsten is used as filament in incandescent lamps, the filament is made straight, coiled or coiled coil form.

→ When the filament is made in straight form, there is a tendency for filament wire to sag if the lamp is operated in horizontal position.

→ To make the filament in coiled form, the wire is wound into a tight coil on a mandrel.

→ Coiled coil filaments are made like, the wire is first coiled on a mandrel, then the coil itself is coiled on another mandrel.

## Carbon

→ carbon materials used in the field of electrical engineering are manufactured from graphite & other form of carbon like coal.

→ The manufacturing process of electrical carbon products consists of following: grinding of raw carbon materials, mixing of the powdered carbon with a binding agent, moulding of the requisite component and lastly baking them.

→ To increase the conductivity of the carbon product, different kinds of additives like copper or bronze powder are mixed with the carbon moulding compound.

→ carbon is used in application like brushes for electrical machines & apparatus, electrodes for electric arc furnace, carbon pile resistances, non wire resistors, membranes and other components for telecommunication equipment, battery cell element, arc lamps, arc welding etc.

## platinum

→ platinum is a greyish white metal which is noncorroding & is malleable and ductile and is resistant to most chemicals.

→ platinum is a heavy metal having specific weight of 21.4 gm/cm². Its melting point is 1775°c. The resistivity of platinum is $0.1 \times 10^{-6}$ Ω-m and its temp. coefficient is 0.00307 per °c.

→ platinum can be drawn into thin wires and strips. It does not oxidize in air and has no tendency to arc.

→ platinum finds application as a heating element in laboratory ovens and furnaces. platinum-rhodium thermocouple is used for measurement of temp. upto 1600°C. platinum is also used as electrical contact material and as material for grids in special purpose vaccume tubes.

→ Materials used for making contacts have to withstand arcing & space over whenever contacts are separated. when materials are used for this purpose they may have to operate under very severe condition particularly when they are subjected to frequent make & break operations.

## Mercury

→ Mercury is a heavy silver white metal. Its specific wt. is 13.55 gm/cm$^2$.

→ It is the only metal which is liquid at room temperature. Its boiling point is 357°C. Its resistivity & temp. coefficient of resistance are $0.95 \times 10^{-6}\ \Omega$-m. and 0.00027 per °C.

→ Mercury is poisonous. In the field of electrical engineering mercury finds application in mercury arc rectifiers, gas filled tubes, as liquid contact material in electrical switches.

## Superconductivity

→ Some metals and chemical compounds whose resistivity becomes zero when their temp. is brought near 0 K. At this stage such metals or compounds said to have attained superconductivity.

→ The transition from normal conductivity to superconductivity takes place almost suddenly over a very narrow range of temp about 0.05K.

→ The temp. at which this transition takes place is called transition temp.

→ There are two types of superconductors known as Type I & Type II. Type I superconductors are soft superconductors & usually pure specimen of some elements. Type II are hard superconductors and usually alloys of metal.

## Superconducting Materials

→ Many metals & compounds have superconductivity property at very low temp.

→ superconductivity has been observed to occur in poorer metallic conductors rather than in better conductors.

→ Superconductors may not be pure metals but various alloys & chemical compounds.

## Application

Electrical machines - Efforts are being made to develop electrical machines and transformers utilizing superconductivity of superconductors can be used as conducting material in addition to superconducting magnets, then it is possible to manufacture electrical generators & transformers in exceptionally small size.

## power cables

superconducting materials of used for power cables will enable transmission of power over very long distance using a diametre of few cm without significant voltage drop & power loss.

18.08.20

Electromagnets - superconducting solenoids which do not produce any heat during operation. superconductivity can be destroyed of the magnetic field exceed critical value. It has been possible to design electromagnets using superconductivity for use in laboratories and for low temp. devices like maser.

## Future prospects

→ All the application requires the conductor to be maintained at a temp. very close to 0°K.

→ This mean that whole of the equipment associated with the conductor has to be kept at near 0°K. This becomes a great challenge for the scientists.

→ presently Helium is used to achieve low temp. required for superconductivity.

→ Helium being an expensive gas, efforts are being made to develop compounds which exhibit superconductivity at temp. possible to be obtained by more easily available & cheaper Hydrogen gas.

# Ch-02 Semiconducting Materials

## Introduction

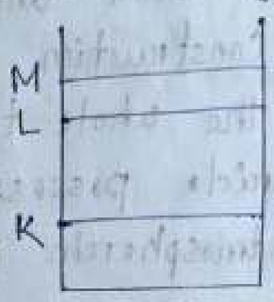
Semiconducting materials have been known for a long
time and were indeed used as crystal detectors in the
crystal set radio. However for many years semiconductors
played a minor role in the electronic industry. Among the
latest application of semiconductors is building of integrated
circuit in which complete circuit function are produced
in a minute piece of semiconductor.

## Semiconductor

It is neither a good conductor nor a good insulator. Typical
semiconductor materials are Germanium and silicon each
of which have four valence electrons.

## Electron energy and energy Band theory


(a) Bohr model of Al atom




(b) Simplified energy level representation of the shells.

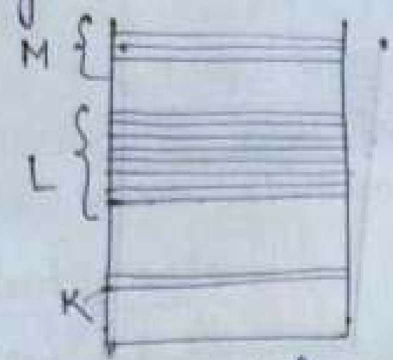
→ An electron revolving around the nucleus of an atom has potential energy, centrifugal energy, rotational energy & magnetic energy, all of which together determine the total energy or the energy level of an electron.

→ The electron volt is defined as that amount of energy gained or lost when an electron moves with or against a potential difference of one volt.

→ All the atom in a given level shall possess the same energy. However atoms donot exist in isolation but in large groups crowded together.

→ The nuclei of neighbouring atom exert force of attraction of varying degree on each other's electron

→ Each level or shell is divided into subshell, each subshell having a different energy level.





(C) Energy level of typical atom (d) Energy levels grouped as Bands

→ In fig(c) each electron now occupies an energy level different from that of any other.

→ In fig (d) The areas between them are called energy gaps. they are also called forbidden zone.

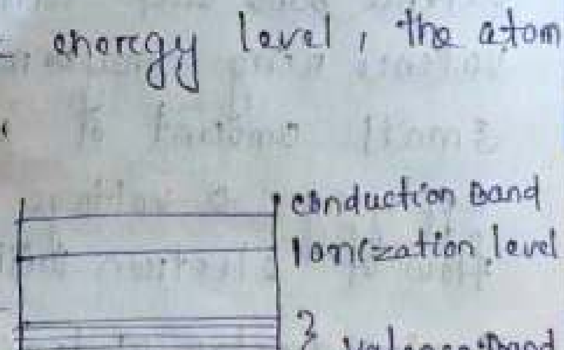
Excitation of atoms

→ when each electron in an atom is in its normal orbit, the atom is said to be in an unexcited state.

→ To move an electron further away from the nucleus requires additional energy. The additional energy can be obtained from light, Heat, Electrostatic, Magnetic & Kinetic.

→ when the electron is in the higher energy level, the atom is said to in an excited state.

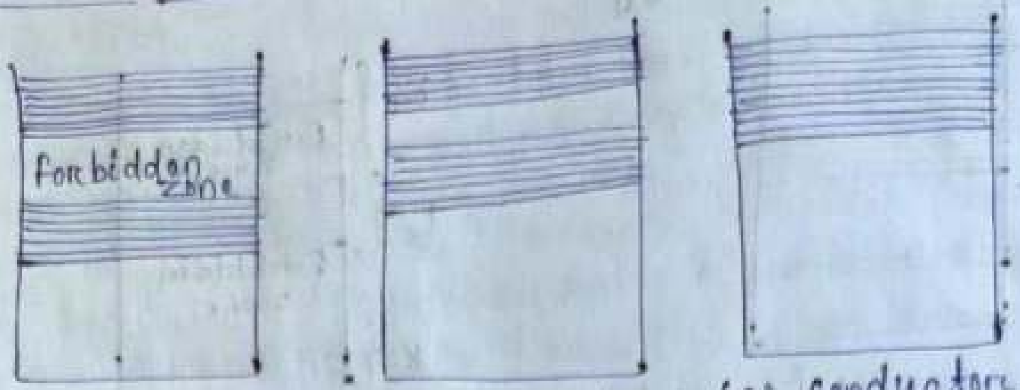
→ When the required amount of light or heat energy is absorbed by a valence electron, it will leave the valence band and may move up to the ionization level. If it does, it is released from the attractive forces of the nucleus.




→ An electron above the ionization level is said to be in the conduction band and is called free electron.

The word ionization level is used because when an electron leaves the valence band, the remaining atom is no longer neutral but has positive charge & is called positive ion.

## Insulator, semiconductors and conductors




(a) Insulator (b) semiconductor (c) conductor

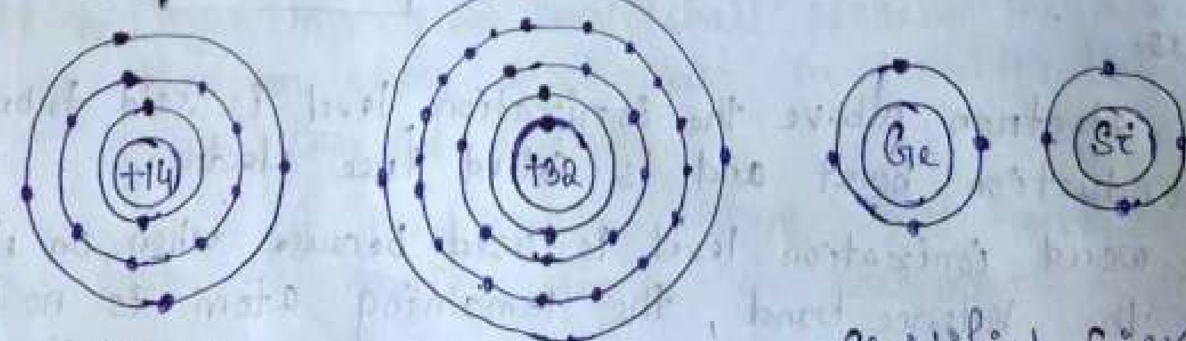
→ In case of insulator, the forbidden zone between the valence band and conduction band is quite large. This indicate electrons in the valence band require large amount of additional energy to move up & become free. As long as the valence electrons are unable to move upto the conduction band there can be no electron flow.

→ In case of semiconductors the forbidden zone is reduced. Thus valence electrons require less energy to free themselves from the attraction of nucleus.

→ In a conductor there is no gap between the valence band and conduction band. Electrons from the valence ring may be moved into the conduction zone by small amount of energy thus becoming free. By applying a voltage across such a material a large flow of electron will result.

## Semiconductor Materials

→ The two most widely used semiconductor materials are Silicon and Germanium.

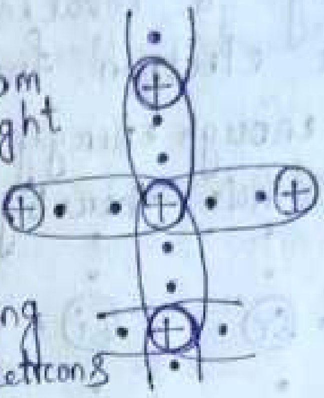



(Si) (Ge) Simplified Si & Ge atoms

→ In the silicon atom K & L shells are full but M shell contains only four electrons. According to $2n^2$ formula the M shell can contain 18 electrons, however the M shell in silicon is the valence shell and thus can never contain more than eight electron.

→ In the Ge atom the K, L & M shell are filled and the N shell is the valence shell containing four electrons.

## Covalent Bonds



→ Covalent bond results when each atom in order to fill its valence ring with eight electrons, shares electrons with its neighbouring atoms.

→ When atoms enter into covalent bonding each atom in effect has eight valence electrons and this it would appear, would result in making such a material a good insulator.

→ Covalent bonding leads to the development of polycrystal, several individual crystal held together imperfectly.

→ Impurities can also cause electrons to be missing from the structure.

→ Energy in the form of light, heat can cause structure disorder.

→ Because of the above reasons, the material does not have perfect crystal structure & is therefore not a good insulator but a poor insulator or is called semiconductor.

## Intrinsic Semiconductor

→ If a crystal Si or Ge does not contain any impurity atoms if it contains only one type of atoms, it is called intrinsic material.

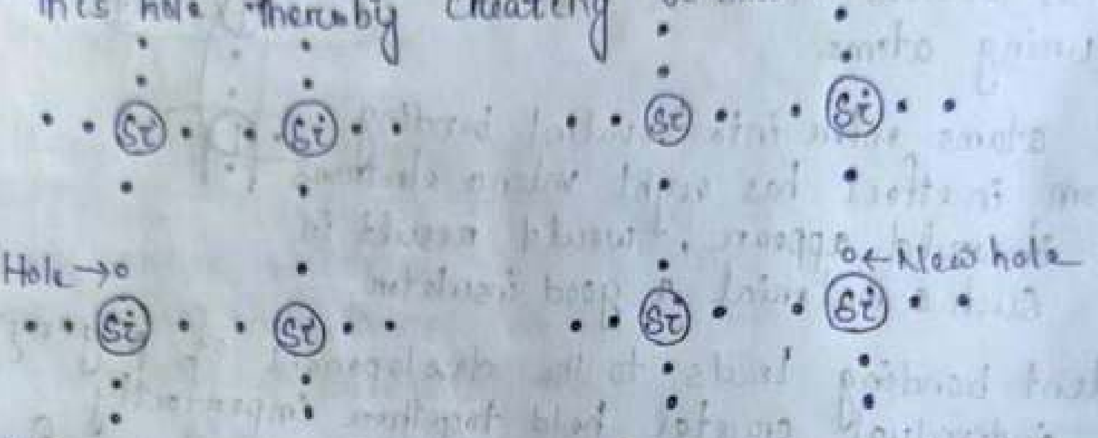
→ If the temp. is brought down to 0°K, this intrinsic material will act as a good insulator & very little current will flow through it.

→ When a voltage is applied to an intrinsic material at a temp. above 0°K, it acts as a conductor

→ The free electrons drift from negative terminal through the semiconductor to the positive terminal.

→ The holes created by free electrons appear to move from positive to negative terminal.

→ This is because when a hole is created by an electron breaking a covalent bond due to thermal energy, a valence electron from neighbouring atom may have just enough energy to break its bond and jump over to this hole thereby creating a new hole.




(Hole movement caused by valence electrons jumping from hole to hole)

## Extrinsic Semiconductors

→ pure Si or Ge exhibit characteristic closer to that of an insulator than a semiconductor. Therefore an intrinsic semiconductor is of little use as a semiconductor except as a heat or light sensitive resistance.

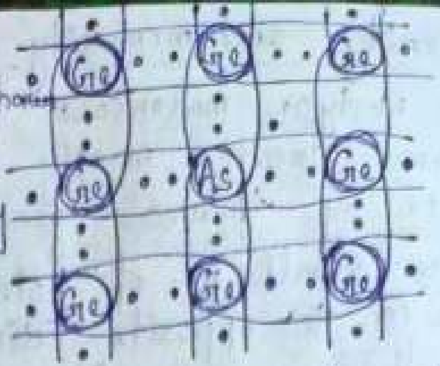
→ In order that the material may function properly as a semiconductor, we must add certain impurities in very carefully controlled quantities.

→ The addition of impurities is called doping. A material which has been doped is called extrinsic material.

## N-type Materials

→ one category of impurities has five valence electrons and is called the pentavalent group.

→ Some of the impurities of this group are Antimony, Arsenic, phosphorus.

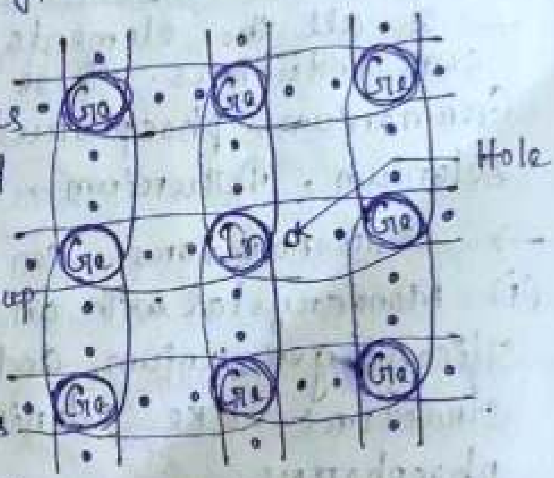



→ when a pentavalent impurity is added to an intrinsic material only four of its valence electrons lock into the covalent bond formation of the atomic structure.

→ The fifth valence electron of the impurity atom is free to wonder through the crystal.

→ Since pentavalent atoms provide an extra electron, they are called donor impurities. A material doped with a donor impurity has excess of electrons in its structure and is therefore known as negetive or N-type material.

P-type Material




→ Another category of impurities has three valence electron and is called the trivalent group.

→ Some of the impurities of this group are Aluminium, Gallium, Indium.

→ when added to intrinsic materials they lock into the crystal structure.

→ Since the impurity has three valence electrons, there is a hole in the covalent bond structure created by the lack of an electron.

→ In order to complete the bond and form a stable eight electron structure a valence electron from nearby atom gains sufficient energy to break loose from its bond and jump into the hole due to attraction from it. This type of impurity is known as acceptor.

→ Intrinsic materials doped with a trivalent impurity are referred to as positive or P-type.

## Majority and minority carriers

→ In N-type materials conduction takes place through free electrons created mostly by doping and small number created by thermal generation.

→ The small no. of holes created by thermal generation move in the opposite direction.

→ Since the no. of free electrons is large they are called majority carriers. The holes being small in number are called minority carriers.

→ In P-type materials holes are the majority carriers and electrons are the minority carriers.

## Semiconductor Materials

→ Of all the elements in the periodic table, eleven are semiconductors. These elements are Boron, carbon, silicon, Germanium, phosphorus, Arsenic, Antimony, sulphur, Selenium, Tellurium, Iodine.

→ Semiconductors can be classified as

(i) Monocrystal with an atomic lattice structure like carbon, silicon, germanium and polycrystal with molecular lattice structure like selenium, tellurium, antimony, arsenic, phosphorus.

(ii) Oxides of such metals such as copper, zinc, cadmium, titanium, molybdenum, tungsten.

(iii) sulphides, selenides & tellurides of lead, copper, cadmium and other elements.

(iv) Chemical compounds of certain elements of the third group of the periodic Table like Aluminium, gallium, indium with those of fifth group like phosphorus, antimony, arsenic.

## Application of semiconductor materials

## Rectifiers

## Ge & Si Rectifiers

→ Ge rectifiers were invented earlier than silicon rectifiers. It is easier and simpler to produce Ge monocrystals.

→ Ge has melting point of 958°c and silicon 1415°c

→ Molten silicon combines readily with practically all chemical elements and is therefore difficult to purify & maintain free from impurity.

→ Ge & Si semiconductors find wide use in both high frequency & supply freq. circuits as noncontrolled & controlled rectifiers.

→ Si rectifiers can operate at temp. upto 200°c. Silicon controlled rectifiers may be considered as a combination of two transistors one n-p-n type and other p-n-p type.

→ Si rectifiers are available for very high PIV rating of the order of 25KV and current rating of the order of 1000 amps.

Copper Oxide and selenium Rectifiers

→ Copper oxide rectifier is a plate of 99.98% of pure copper on which a film of cuprous oxide is produced by special process.

→ one side of the plate is cleaned of cuprous oxide and an electrode is soldered directly to the copper. The second electrode is soldered to cuprous oxide film.

→ copper oxide rectifiers are available for low PIV and current rating.

→ copper oxide rectifiers are comparatively cheaper than Si rectifiers.

→ Selenium rectifiers use more than 99.99% pure selenium. crystalline selenium has melting point of 220°c is used for making rectifiers.

→ selenium rectifier has a greater permissible density & wider working temp. range as compared to copper oxide rectifier.

→ Both copper oxide and selenium rectifiers are protected against moisture by giving their elements a coating of insulating varnish.

## Temperature sensitive resistors or thermistors

→ Increasing the temp. of semiconductor materials causes their resistance to decrease. This property has found application in devices called thermistors.

→ They are made from oxides of certain metals such as copper, manganese, cobalt, iron, zinc.

→ Thermistors find application in temperature measurement and control. They sense temp. variation and convert them variations into an electrical signal which is then used to control heating devices.

## photoconductive cells

→ The resistance of semiconductor material is low under light & increase in darkness. This phenomenon is used in photoconductive cells where a semiconductor material is connected in series with voltage source.

→ photoconductive cells can be used in application which require control of certain function or events according to colour or intensity of light.

## photovoltaic cells

→ photovoltaic cells are devices that develop an emf when illuminated. Thus they convert light energy directly into electrical energy.

## varistors

The resistance of semiconductors varies with the applied voltage. This property is used in devices called varistors. Use of varistors is made in voltage stabilizers and motor speed control.

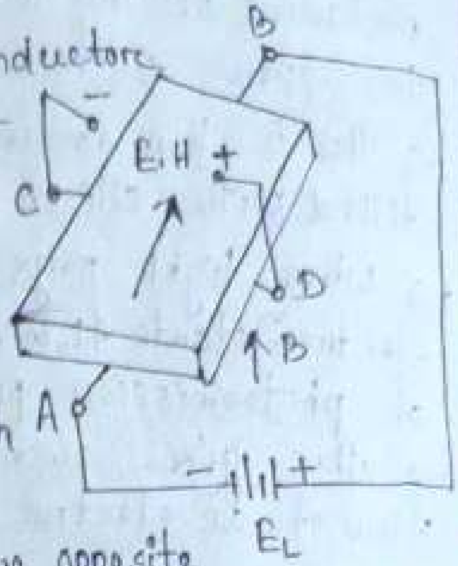
## Transistors

→ The resistance of semiconductor depends to a large extent on the magnitude of electric field.

→ A transistor is a two junction three terminal device. the two junction being formed by joining P, N & P material or N, P & N materials.

→ Transistors have replaced the vaccume & gas tubes in performing many job including amplification of signals & switching circuits.

## Hall effect generators




→ when current flows through a semiconductor bar placed in a magnetic field, a voltage is developed at right angles to both the current & the magnetic field. This voltage is proportional to the current and the intensity of the magnetic field.

→ Consider a semiconductor bar which has contacts on all four sides.

→ If a voltage $E_L$ is applied across two opposite contacts A & B a current will flow. If the bar is placed perpendicular to a magnetic field B, an electric potential $E_H$ is generated between the other two contacts C & D. This voltage $E_H$ is a direct measure of the magnetic field strength and can be detected with a simple voltmeter.

## Strain gauges

→ semiconductors besides being sensitive to heat, Light, voltage and magnetic field are also sensitive to mechanical forces

→ If a long thin rod of silicon is pulled from end to end its resistance increases. because mechanical force pulls each silicon atom slightly away from adjacent atom.

→ silicon and other semiconductor material make very sensitive strain gauge which are devices used to measure small changes in the length of solid objects.

## Solar power

→ Sun is the vast source of energy. Many practical devices have been developed due to a lot of research work.

→ one of its important application is the conversion of solar power into electrical power. This phenomenon is called photovoltaic effect.

→ Solar cell is basically a thin disc of P-N junction with a large surface area. A very thin layer of P-type material of the order of few microns is diffused on the upper surface of the disc to form a shallow P-n junction.

→ This is then enclosed in a glass container with the top surface filled with a silicon grease to prevent losses by reflection.

→ when light rays fall on the surface of this arrangement electron starts flowing from n-plate to the p-plate by means of photoemission process.

→ This gives rise to potential difference and constitute flow of an electric current.

→ A solar cell is developed in the form of a slice of single crystal silicon. The typical size is 20mm × 20mm × 300μm.

→ The output depends on the intensity of sun rays. As the cell is turned away from the sun, the output decreases as the cosine of the angle of incidence

→ The presence of moisture or carbon dioxide in the atmosphere affects adversely to the performance of solar cell.

→ Application of solar cell are small power source such as in watches, calculators, telephones in rural areas, solar water heater, solar pump, space research work etc.

# Ch-03 Insulating Materials

Any material that is able to insulate i.e to prevent the flow of electricity through it when difference of potential is applied across it is called insulators.

02.09.20

## General properties of insulating material

Different properties are
(i) visual properties
(ii) Electrical properties
(iii) Mechanical properties
(iv) chemical properties

## Electrical properties

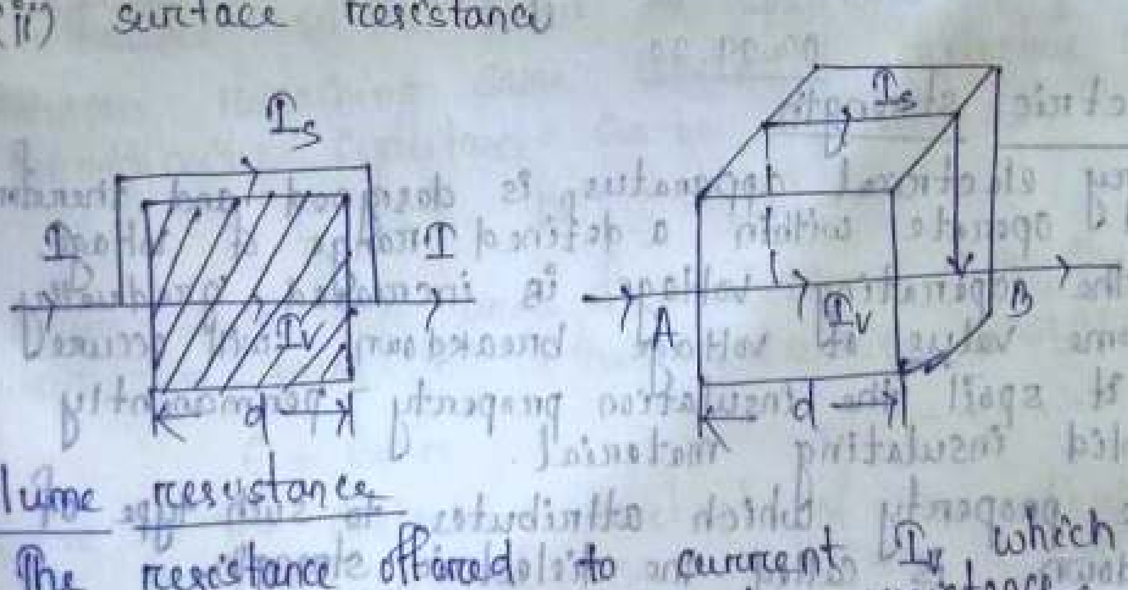
The primary function of an insulating material is electrical

### various electrical properties

This is a property by virtue of which a material resists the flow of electric current. It should be as high as possible. when subject to electrical pressure there will always be a flow of current. An insulator to which a voltage V is applied will have a small current I flowing through it. The insulation resistance is given by

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

Insulation resistance is of two types
(i) volume resistance
(ii) surface resistance




### volume resistance

→ The resistance offered to current $I_v$ which flows through the material is called volume resistance.
→ The resistivity is the resistance offered to the flow of current through the body of the material & is expressed in ohm-m.

→ Thus volume resistance of insulating material is given by $R_V = \rho_V \frac{d}{a}$

where $\rho_V$ — volume resistivity

d — is the length of current path through the material

a — c/s area of current path

Surface resistance

The resistance offered to current $I_s$ which flows over the surface of insulating material is called surface resistance. Surface resistivity depends upon humidity.

Effect of various factors on insulation Resistance

(i) Insulation resistance is very much affected by temp. variation.

(ii) Exposure to moisture produces marked decrease in the surface insulation resistance.

(iii) The value of insulation resistance is also affected by the voltage applied and to small extent by the direction in which voltag is applied.

(iv) The resistance of insulating material decreases with age

03.09.20

Dielectric strength

→ Every electrical apparatus is designed and therefore should operate within a defined range of voltage

→ If the operating voltage is increased gradually at some value of voltage breakdown will occure and it spoil the insulation property permanently in solid insulating material.

→ The property which attributes to such type of breakdown is called the dielectric strength.

→ Dielectric strength is the minimum voltage which when applied to an insulating material will result in destruction of insulating properties.

→ Dielectric strength is the maximum potential gradient that the material can without rupture.

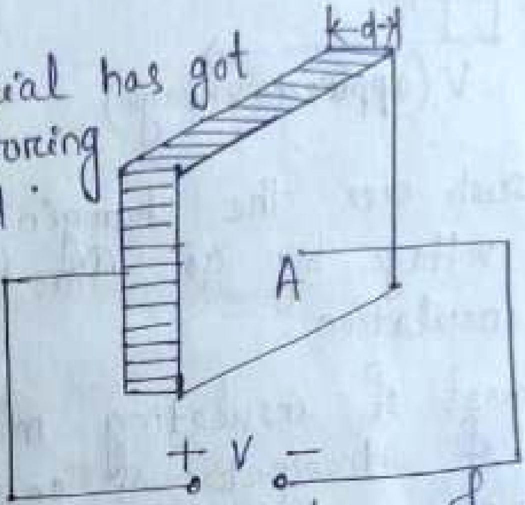
## Factor affecting dielectric strength

→ Dielectric strength decreases with rise of temp. in case of air.

→ Humidity generally decreases the value of dielectric strength.

## Dielectric constant

→ Every insulating material has got the basic property of storing charge when voltage applied across it. This charge is proportional to the voltage applied




$Q \propto V$

or $Q = CV$

where C is called capacity or capacitance of the material across which the voltage is applied.

→ capacitance is different for different insulating material. The property of insulating material that causes the difference in the value of capacitance, physical dimension remaining same is called dielectric constant or permittivity. Capacitance can be expressed as

$$C \propto \frac{A}{d} \quad \text{or} \quad C = \epsilon \frac{A}{d}$$

where A is face area of insulation, d is the distance between two faces. $\epsilon$ is the dielectric constant.

$$\epsilon = \epsilon_0 \epsilon_r$$

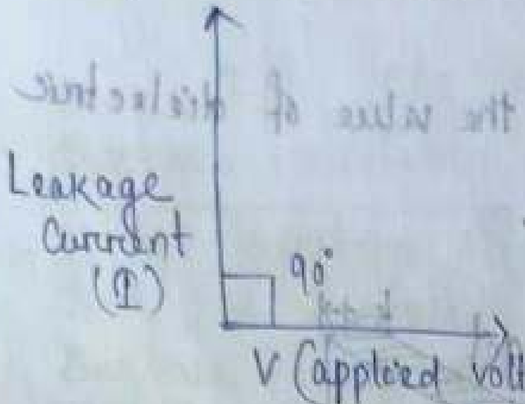
$\epsilon_r$ is the dielectric constant of the material and $\epsilon_0$ is dielectric constant or permittivity of vaccume.

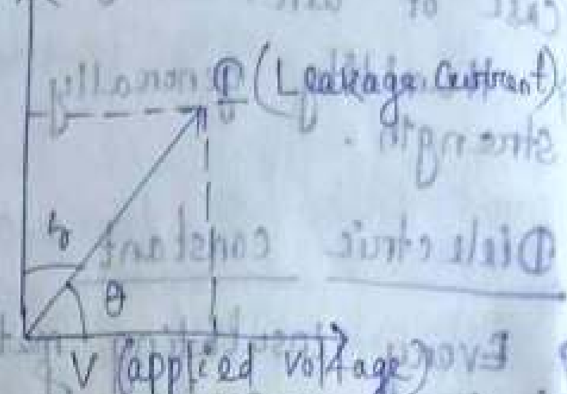
$$\epsilon_0 = 8.854 \times 10^{-12} \text{ F/m}.$$

→ Temp. and humidity also affect the dielectric constant

08.09.20 Dielectric loss

→ When a perfect insulation is subjected to alternating voltage it is like applying alternating voltage to a perfect capacitor. In such case there is no consumption of power.




→ In such case the charging current would lead the applied voltage by 90°. This means there is no power loss in the insulation.

→ In most of insulating material there is a definite amount of dissipation of energy when an insulator is subjected to alternating voltage. This dissipation of energy is called dielectric loss.

→ In commercial insulator, the leakage current does not lead applied voltage by 90°. The phase angle is always less than 90°. The complementary angle $\delta = 90 - \theta$ is called dielectric loss angle.

→ For an insulator having capacitance C and voltage applied V to it at a freq. of f Hz, the dielectric power loss is given by

$$P = VI\cos\theta$$

$$= V \times \frac{V}{X}\cos\theta$$

$$= V^2 2\pi f c \cos\theta = V^2 2\pi f c \sin\delta$$

In most insulator δ is negligibly small

$$P = V^2 2\pi f c \tan\delta$$

tan δ is called power factor of insulator.

## Factors affecting Dielectric loss

→ The loss increases proportionately with the frequency of applied voltage.
→ presence of humidity increases the loss.
→ Temp. rise normally increases the loss.
→ voltage increases causes increased dielectric loss

## Visual properties

The following are the visual properties of insulating materials.
(a) Appearance
(b) colour
(c) crystallinity

09.09.20

## Mechanical properties

Some of the mechanical properties are
(a) Mechanical strength – Most solid insulators have to withstand various loads during manufacture as well as during operation when used in an apparatus.
→ Strength requirement is very basic although the magnitude may different for different application.
The mechanical strength of insulating material depends upon
(i) Temperature rise
(ii) climatic effects
(b) viscosity – Viscocity in liquid dielectrics will affect manufacturing process! In paper insulated cable the temp. at which the oil will penetrate through the paper will depend on its viscosity.
(c) porosity – High porosity insulating material will increase moisture holding capacity and adversly affect electrical properties.
(d) solubility – In certain application insulation can be applied only after it is dissolved in some solvent. In such case

insulating material should be soluble in certain appropriate solvents

(2) Machinability and mouldability – These properties are important from point of view of economic mass production.

10.09.20

## Thermal properties

→ one of the major function of insulation is heat transfer

→ consider an underground cable under operation which is recommended for operation with certain limitation of voltage & current.

→ suppose the voltage is increased, If the involved insulating material is able to withstand high voltage stress the change will cause increase of dielectric loss that will cause heat generation.

→ If the load current in the cable is increased, $I^2R$ losses will increase resulting once again in increased heat generation and failure

Various thermal properties are

Melting point, Flash point, volatility

→ Melting point assumes importance in specific cases like nondraining compound paper insulated cable.

→ In the entire operating temp. range of cables the impregnating compound must not melt to avoid migration of oil.

→ volatility assumes importance from the fact that when a trapped gas is evolved from a volatile insulating material subjected to voltage stress.

Thermal conductivity

→ Heat generated due to $I^2R$ losses and dielectric losses will be dissipated through insulator itself.

→ An insulator with better thermal conductivity will not allow temp. rise because of effective heat through it to the atmosphere

## Thermal expansion

→ An insulator with high coefficient of expansion poses problem.

→ Repeated load cycle of apparatus cause corresponding expansion & contraction of insulator leading to possibility of the formation of voids in it.

→ When there are two insulating materials involved to form an insulation system different coefficient of expansion of the two will further increase the formation of voids. These voids have been found to be the major cause of insulation breakdown.

## Heat Resistance

→ This is a general property which desires that a dielectric should withstand temp. variation within desirable limits, without damaging other important properties.

→ If an insulator has favourable properties at ambient temp. but is not able to retain these properties to desirable extent at high temp. upto which it has to operate, it is not a good insulator.

→ The current loading can be increased thus making the apparatus capable of handling more power. This favours the economy.

15.09.20

## Chemical properties

### Chemical Resistance

→ presence of gases, water, acids, alkalis and salt affect different insulator differently.

→ chemically a material is a better insulator if it resists chemical action.

→ Certain plastics are found approaching this condition. Their use is very much on the increase.

→ plastics have replaced paper insulation in many application because the former being chemically inert and hygroscopic

→ Chemical resistance requirement of insulation used in underground cable are likely to operate under

Severe chemical condition due to water, salt, acid & alkalis will be more demanding than those of the insulation used in motor winding.

Hygroscopicity

→ Many insulators come in contact with atmosphere either during manufacture or operation or both. The contact of insulation with atmosphere is often so complete that even the less chemically aggressive atmosphere can prove a threat to the smooth running of apparatus.

→ Moisture due to high humidity atmosphere can affect insulator
(i) It act on surface of insulation
(ii) It may be absorbed by the insulation.

However there are insulating materials like paraffin, polythene, polytetrafluroethylen which are nonhygroscopic

Ageing

It is the long time effect of
(i) Heat
(ii) chemical action
(iii) voltage application

These factors decide the natural life of an insulation and thus of an apparatus.

Insulating Materials - Classification, properties & application

→ There are thousands of insulating materials available in the market.

→ Insulation technology is one of those few branches where the number of materials is very large.

→ Any special requirement can be served by some special material.

→ The very advantage offered by existance of a large variety of insulating material available to choose from may turn into desadvantage if the concerned person is not equiped properly with the required skill.

→ The technique to choose the right material out of an ocean of material is to equip ourselves with the right tool.

An ideal insulating material should possess

(i) Dielectric strength as good as that of mica.

(ii) volume & surface resistivity equal to that of sulphur.

(iii) Mechanical strength as good as that of steel.

(iv) crushing resistance as good as that of granite.

(v) Ease of machining as good as that of wood.

(vi) Fire proofing qualities as good as that of silica.

(vii) chemical inertness equal to that of platinum

(viii) surface finish like that of ebonite.

(ix) water proofing quality as good as that of paraffin wax.

16.09.20

## Classification of insulating material

Insulating materials on the basis of their physical & chemical structure may be classified in various catagories

(i) Fibrous materials

(ii) Impregnated fibrous materials

(iii) Non resinous materials

(iv) Insulating liquids

(v) Ceramics

(vi) Mica & mica products

(vii) Asbestos & asbestos products

(viii) Glass

(ix) Natural & synthetic rubber

(x) Insulating resins & their products

(xi) Laminates, Adhesives, enamels & varnishes

## Fibrous materials

→ These are either derived from animal origin or from cellulose which is the major solid constituent of vegetable plants.

→ The majority of materials are from cellulose.
Different fibrous materials are

(a) wood –
→ It was in the past frequently used for low voltage installation.
→ This is light in weight with relative density varies betn 0.5 & 1
→ Tensile strength varies depending on kind of woods is between 700 & 1300 kg/cm²
→ Temp. is obviously a limitation. wood is very hygroscopic & after absorbing moisture tends to loose its mechanical properties.
→ In early days cheapness, ease of availability, fabrication were the reason for its use as structural material for transmission & distribution poles.

(b) paper & cardboard
→ The base material for manufacturing insulating paper is coniferous wood.
→ The organic contaminants like lignin & pentosan must be properly removed.
→ crushed wood is boiled after adding some alkaline reagents. The process is called sulphate process.
→ paper insulation duly impregnated has been used very successfully in apparatus for generation, transmission & utilization of electric power.
→ The use of unimpregnated paper is very limited because of certain major limitation which are
(i) Hygroscopicity (ii) Reaction with oxygen (iii) Thermal instability.

(c) Insulating Textiles
→ Textiles are woven from fibrous materials like cotton, Jute & hemp.
→ sometimes silk from animal origin is also used for special purpose

→ This class of material are mechanically strong in tensile strength.

(d) cotton

→ It is made in the form of fibre or cloth and tapes for the purpose of promoting insulation.

→ It is available in any colour as per the requirement.

→ It is combustible & chars when heated even without the presence of sufficient air & oxygen.

→ It is a porous material & absorb water quickly.

→ Cotton covered wire is widely used for winding of small & medium size machines, chokes and small transformer coils etc.

→ The operating temp. of cotton is 100°C and at high temp. it gets carbonized.

(e) silk

→ It is protein fibre consisting of long chain structure similar to that of cellulose.

→ The silk yarn clothes are thin & strong. It has better factor than copper but it is quite expensive.

→ Its electrical characteristic are better than cotton but is more hygroscopic.

→ Natural silk is used in application where space is of prime importance in instrument meters & other measuring instruments.

→ Artificial silk is less affected by water and has coarse fibre and less elastic as compared to natural silk.

f) Jute

→ It is made from cellulose. Its fibres are thicker & is similar to cotton cloth but cheaper in cost.

22.09.20

Impregnated Fibrous Materials

→ proper impregnating compound into fibrous material resulted in some very stable insultating materials.

→ It is by proper impregnation that limitation like hygroscopicity and thermal & chemical degradation of unimpregnated fibrous materials are overcome.

(a) Impregnated paper dielectrics

→ Among all fibrous materials used as insulators this class contributes the maximum.

→ paper insulation is usually provided on the conductor without impregnation. After the conductor with unimpregnated paper is placed in position in any apparatus the semi-finished apparatus is then put through the impregnation process. ~~which~~

Main features of impregnated paper insulation →

(a) Good mechanical properties
(b) Good chemical stability
(c) Ability to withstand high temp.
(d) Dielectric constant varying betn 2.25 & 6.35.
(e) Comparatively less dielectric loss
(f) Non inflammable

Application →

(i) cables : In all type of cables i.e underground power cables, mining cables and submarine cables in the operating voltage range of 220V to 400KV.
(ii) Transformers : paper dielectric is frequently used in high voltage power transformers.
(iii) capacitors

B) Varnished or impregnated Textiles

→ cotton or silk textiles can be varnished by two types of varnish. (i) oil varnish (ii) ~~oleo~~ oleobituminous varnishes.

Main features →

i) Good mechanical strength
ii) Good dielectric strength
iii) Low hygroscopicity.
iv) Low resistance to organic solvents.
v) Limiting working temp. of 105°c.
vi) oleobituminous varnished textiles are not resistant to oil.

Application →

→ This insulation is widely used for winding in electric machine of low & medium ratings. It is also used in cables as wrappers & liners.

Nonresinous Materials

→ solid or semisolid insulations which are directly available in nature and are organic based fall under this class. These materials are mineral waxes, asphalts, bitumens and chlorinated naphthalene

Nonresinous materials are classified as

(A) Bitumens: These are solid or semisolid materials obtained by refining crude petroleum.

Special features of bitumens are

(i) Highly soluble in mineral & synthetic oil.
(ii) Easily oxidized.
(iii) Resistant to moisture penetration.
(iv) poor insulating property.
(v) Acid & alkali resistant.
(vi) specific gravity is about one.

Application of bitumens:

→ Bitumen is normally used in electrical engineering because of its outstanding property of being water resistant. It is very cheap.

→ Bitumen compounded paper, hessian & cotton tape are widely used in the manufacture of underground cable to provide bedding & serving for steel armour.

(B) Waxes : 23.09.20

(a) paraffin & microcrystalline waxes

→ These waxes are obtained by the process of distillation of mineral petroleum oil.

Special features :

(i) Easily soluble in mineral & synthetic insulating oil.

(ii) Mechanically weak.

(iii) poor electrical properties which becomes poorer when heated.

(iv) paraffin waxes get oxidized when they are heated beyond melting point.

Application :

→ The excellent sealing property of waxes makes them fit for use as sealing material.

→ These cables are extensively used in India for transmission in urban areas.

(b) Natural waxes

→ Natural wax is often used, after processing in the form of chlorinated paraffin wax.

→ Natural wax also suffers from shrinkage or expansion when undergoing change of state.

→ Dielectric constant ranges betn 2 & 3. The melting point of natural wax may be upto 130°C

Application :

→ These wax are mixed with insulating oil to improve the viscosity and pour point of the latter to form nondraining cable compound.

Insulating liquids

→ These liquids apart from working as insulation fulfil other important requirement like (a) they are able to improve insultating properties of other solid materials by eliminating air and other gases (b) they offer good heat dissipation media (c) they are sometimes required for extinguishing arc in certain application like circuit breaker

Application →

→ These liquids are finding use in application like capacitors & transformers.

→ Apart from mineral & synthetic liquid there are some other type of liquids are used in specialized application like high freq. capacitors and high temp. stability requirements.

→ Mineral oils, askarels, vegetable oils are liquids used in the normal operating temp. of -50°C to 130°C.

→ Flourinated & silicon liquids are utilized in high temp. range of -50°C to 200°C.

Main features of insulating liquids →

The effect of some factors on these oils are

(i) oxidation – Most of the liquids are susceptible to oxidation whose effect is further increased with increase in temp.

→ oxidation impairs electrical properties, especially the dielectric loss.

→ To overcome the ill effect of oxidation we must either prevent oxidation or remove the oxidized part periodically.

→ prevention of oxidation is caused by (a) not letting air in contact with oil for more time than is absolutely necessary, (b) use of conservators (c) use of inhibitors

(ii) Moisture – This is soluble in most of the insulating liquids resulting in decreased dielectric strength, increased dielectric losses and increased oxidation.

→ Insulating oils absorb moisture in varying degrees depending upon the type. Those oils are preferred which absorb less moisture.

→ The moisture in oils should be avoided because of the fact that it increases oxidation which enhances the deterioration of oil.

→ Removal of moisture from insulating oil is mainly done by dehydration process.

(iii) Temperature – Temp. rise increases the oxidation of liquids. Temp. rise also increases the gas solubility of liquids which adversely affect their insulating properties.

29.09.20

## Ceramics

→ These are materials made by high temp. firing treatment of natural clay and contain inorganic matters.
→ structurally, ceramics are crystal bonded together
→ other materials used with clay in different type of ceramics are Alumina, quartz, Talc, magnesite, feldspar etc. A few of the known ceramics are composed

Insulator porcelain : clay, quartz, feldspar
High freq. porcelain : clay, quartz, barium carbonate
steatite : clay, Talc, Magnesite

Main features of ceramics →
(i) Ceramics are hard, strong & dense
(ii) Not affected by chemical action except by strong acids and alkalies.
(iii) stronger in compression than in tension.
(iv) stability at high temp. likely to occur in electrical engineering application.
(v) Excellent dielectric properties.
(vi) weak in impact strength.

Application –
Major applications are
(a) porcelain insulator – porcelain ~~insulatogra~~ materials are used to make many different type of insulators, like transformer bushing pins, suspension insulators for transmission and distribution lines, disconnecting switches, porcelain parts used for switches, plug & sockets, fuse holders, telephone insulators etc.
(b) Line insulators – porcelain finds one of the largest application as line insulators. Rain & dirt affect surface resistivity.

(C) Other Ceramic Material

→ Apart from porcelain there are other ceramics. Relatively high loss factor and its further increase at high temp. and freq. has restricted the use of porcelain.

(i) Steatite – A proper mixture of clay & talc dried & then fired with addition of certain other materials like felspar, magnesite etc makes steatite.

(ii) Alumina – This is primarily made of Aluminium oxide. Extremely high firing temp. (1750°c) and other factors make manufacturing difficult.

(iii) Titanate ceramics – Inclusion of certain titanates like barium titanate, lead titanate etc. during manufacture make titanate ceramics. Titanate ceramics have an astoundingly high dielectric constant.

(iv) Oxide free ceramics – There is another class which has been developed in which there are no oxides. Instead of oxides they consist of nitrides, sulphides, carbides etc. The melting point of nitride exceeds 2000°c & this can be used at a temp. as high as 1700°c in oxygen free medium.

Mica & mica products

→ Mica is an inorganic mineral. It is one of the best natural insulating material available.

→ It is one of the oldest insulation of outstanding performance. About 80% of total world requirement of mica for electrical industry is furnished by India.

There are two type of mica are there

a) Muscovite mica: Chief source of supply are India, Brazil & U.S.A. but the best is available in India. The basic chemical composition of Muscovite mica is $KH_2Al_3(SiO_4)_3$. The general properties are

→ strong, tough & less flexible.

→ colourless, yellow, silver or green in colour.

→ Insulating properties are very good.

→ Abrasion resistance is high.

→ oils & hydrofluoric acid act on it adversely. Alkalies donot affect it.

Application

→ Muscovite mica is generally used where electrical requirements are severe. High dielectric strength allows it to be used in capacitors. High abrasion resistance enables its use in commutators.

(b) phlogopite Mica

→ principal sources of supply are Malagasy, U.S.A & Canada. The basic chemical composition is KH (MgF) Mg AlSi. It is also called magnesium mica.

Some of the properties are

(i) Amber, yellow, Green or grey in colour.

(ii) Greater structural stability, being tougher & harder than muscovite mica.

(iii) Resistant to alkalies but less to acids.

(iv) Insulating properties are poorer than those of muscovite mica.

Application:

→ phlogopite mica is used when there is greater need of thermal stability as in domestic appliances like irons, hot plates, toasters etc

Mica products

Natural mica has been found to have limited industrial application because of its poor chemical & insulating properties. It also possess manufacturing difficulties because of unfavourable physical & mechanical properties. Some important mica products are glass bonded mica, synthetic mica, Mica paper, manufactured mica.

Asbestos & Asbestos products

→ It is the term used to designate a class of naturally occuring long fibre minerals.

→ These fibres are strong & flexible and some varieties are even suited for spinning into different Textiles. Two types of asbestos are naturally available

Chrysotile Asbestos

→ principal sources of supply are Canada & Africa.
→ specific gravity is 2.0-2.8.
→ It is highly hygroscopic.
→ It exhibits relatively high dielectric loss & low dielectric strength.
→ It is never used in high voltage application.

Amphibole Asbestos

→ principal sources are south Africa & Alaska.
→ It does not lend itself to easy spinning because the fibres are either too soft or too hard and brittle.
→ compared to chrysotile asbestos it possesses a good tensile strength.
→ Highly hygroscopic.

Application

→ Asbestos is used in low voltage work as insulation in the form of rope, tape cloth and board.
→ In all such uses it is normally impregnated with a liquid or solid like resin.
→ proper impregnation improves the mechanical & electrical properties.
→ It is used as insulation in wires and cables under high temp. condition, in coil windings & in end turn insulation in motors & generators, as conductor insulation and layer insulation in transformer, as arcing barrier in switches & circuit breaker.

Industrial Asbestos products

Some of the asbestos products are

(i) Asbestos roving – chrysotile asbestos fibres reinforced with cotton or synthetic organic fibres make asbestos roving. It finds use in insulation of cables & conductors and in heating devices.

(ii) Asbestos paper & board – In actual use asbestos paper is further reinforced with cotton or synthetic fibre or glass. Asbestos paper is applied as wrapper, barrier insulation in transformer, insulation for wires & cables.

(iii) Asbestos tapes – Tapes are made by weaving asbestos yarn and then either varnished or resin impregnated. Asbestos tapes are used for equipment required to work at temp. higher than those recommended for class A insulation.

(iv) Woven asbestos types – Asbestos cloth is woven from asbestos yarn. It is used in moulded & laminated structure for electrical or mechanical purpose.

<u>Glass</u>

→ It is an inorganic material made by the fusion of different metallic oxides.

→ It is normally transparent, brittle & hard.

→ It is insoluble in water & the usual organic solvents.

→ Different oxides involved in the manufacture of glass are those of silicon, boron, phosphorus, sodium, potassium, zinc, calcium, lead etc.

→ Silicon oxide is invariably used in the manufacture of glass.

<u>Application</u>

→ Glass is used very widely as moulded insulating devices such as electrical bushings, fuse bodies, insulators etc. It is used as a dielectric in capacitors.

→ Radio & television tubes, electrical lamps, laminated boards also make use of glass in abundance although not as conventional insulator.

<u>Various commercial varieties of glass are</u>

(a) Fused quartz or silica Glass – Silica when heated to the temp. of fusion and then cooled is known as silica glass. The material excels in low coefficient of expansion & good electrical properties like low power factor & high resistivity.

b) Borosilicate Glass – This glass requires about 28% oxide of boron along with other oxides. These glasses possess good electrical properties but not as good as that of quartz.

(c) Fibre Glass Insulation – one of the major limitation of cellulose insulation is that it cannot be operated at temp. of 130°c and above. Fibre glass products are less hygroscopic and donot degrade at high temp.

(d) Epoxy Glass – The epoxy glass is made by joining glass fibre layers with a thermosetting compound. Its main features of non absorbant of watch and immunity with alkalies & acids makes it suitable to be used in PCB making terminal holders and instrument case etc.

Natural and synthetic Rubbers

Natural rubber is obtained from the milky sap of special trees. It finds very limited application in engineering. The reasons are that it is rigid when solid, sticky when warm and it get oxidised when exposed to atmosphere. Rubber is a material which is stretchable to more than twice its original length without permanent deformation. Rubber is that class of elastic material which is made usable by vulcanization process and which is stretchable without any permanent deformation.

(a) Natural Rubber : Natural rubber is extracted from milky sap collected from special trees, water is then evaporated out. For engineering use it is further masticated by passing it through warm rollers repeatedly. Additives like sulphur, oxidation inhibitors like aromatic amino compound, softners like vegetable oils and fillers like carbon black, & zinc oxide or magnesium carbonate are mixed to it. The mixture is now ready for vulcanization when sulphur between 4 to 45% depending upon requirement is added.

Application : It finds its limited use in covering wires, conductors for low voltage operation.

(b) Hard Rubber : Increased sulphur content & extended vulcanization treatment gives a rigid rubber product. The properties of hard rubber are good electrical properties and high tensile strength. Maximum permissible operating

temp. is 60°C. continued exposure to sun is harmful.
Application : This material finds its use in construction of storage battery housing, panel boards, bushings of Various types.
Other rubbers are Butadiene rubber, Butyl rubber, Chloroprene rubber.

Insulating resins & their products

These materials are of two types : first type is the naturally occuring materials like air, mica, asbestos etc. The other type is those which are easily derived from nature like cellulose, vulcanized rubber, ceramic, mineral oils etc. plastics are organic materials of higher molecular weight and are capable of being formed into a desired shape during or after their manufacture.
plastics or resins can be of two types.
(a) Natural Resins
(b) synthetic Resins

(a) Natural Resins : They are derived from plant and animal Sources. Natural resins do not dissolve easily in mineral oils at room temperature 300°c to 350°c.
Application : shellac finds its use as binder material in the manufacturing of mica tapes, commutator insulation etc. wood resin is used for paint and varnish application.

(b) synthetic resins : These are made by the recurring chemical reaction of a simple organic compound combined together to form a high molecular weight composition. Resins are more rightly termed as resin polymers.
Some of the resin polymers are
Thermoplast Resins
A. cellulose derivatives
(i) Cellulose Acetate
(ii) Cellulose nitrate

b) polyhydrocarbons
i) polyethylene
ii) polystyrene
iii) polystyrene fluoroethylene

C) vinyl polymers
(i) polyvinyl chloride
(ii) polyamide resins
(D) polycarbonate resins
(E) Linear polyster Resins.

Laminates & Adhesives : Enamles and varnishes

Laminates : when multiple, thin layers or sheets of insulating materials like that of paper, cloth, mica, glass etc are bonded together by a suitable binder for certain specific insulation applications, the composite insulation is called laminate.

Application : paper reinforced laminates are used in transformer, printed circuit etc. Asbestos reinforced laminates are used for high temp. installation. Glass & reinforced laminates are used in printed circuits used for high frequency work.

Adhesives : Adhesive or binder is a class of material compositions required to carry out bonding between two or more solid surfaces in order to prevent independent motion of the binding surfaces.

Application : Adhesives are used in the manufacture of laminated structures in applications like insulated boards, coil winding cylinders, rods, tubes & special shaped insulators.

Enamels : Enamel is a fusible insulated coating of normally some organic base material which is generally applied on conducting surface.

Application : It finds extensive use in coating wires used for the windings of low rated motors, transformers, various types of instruments etc.

Varniches: varnish is a liquid, usually a solution of resinous matter in an oil or a volatile liquid which when applied to a surface dries by either evaporation or by chemical action, resulting in hard shining coating which is resistant to air & water.

Some of the varnishes are

(i) Black varnishes – These are used in the manufacture of varnished cloth, as impregnant for winding armature coils etc.

(ii) oil varnishes – These are used in the manufacture of light varnished fabrics. They are also used as impregnant for transformer windings.

(iii) cellulose Resin base varnishes – These are very rarely used.

(iv) Alkyd Resin – These varnishes are used for coating electrical apparatus in order to provide surface discharge resistance and for impregnation of the winding of oil filled transformer.

Insulating Gases

Simple gases air & nitrogen are commonly in use as insulator. However electronegative gases such as Freon sulphur hexaflouride are now-a-days in use because of certain advantages.

Commonly used insulating gases →

→ Air – Like other insulating gases, the dielectric constant of air increases linearly with increasing gas pressure. Air act as insulation in many electrical application in addition to the solid or liquid insulating material provided. Examples are overhead transmission line, condenser, plugs, switches etc

→ Nitrogen & Hydrogen – Like air nitrogen is also commonly used as insulator in electrical equipment. In many application nitrogen is used for both electrical & chemical purposes. In many high voltage application air is replaced by nitrogen to prevent oxidation of the other insultaing material and thus to reduce their rate of deterioration. Nitrogen under pressure is used as the only insulator in certain types of capacitors. Hydrogen is rarely used as an insulator. It is commonly used for cooling purposes in electrical machines.

→ Sulphur-hexaflouride : when sulphur is burnt in an atmosphere of fluorine, sulphur hexafluoride is formed. It has high dielectric strength and is non inflammable. It is characterized by cooling property which is superior to those of air and nitrogen. At increased pressure, its dielectric strength increases and may even become equal to that of mineral transformer oil. It has found application in transformers and electric switches. To have high dielectric strength, this gas must be used under high pressure which needs a sealed tank construction capable of withstanding the pressure over the whole temp. range of its commercial use. sulphur hexaflouride possesses a high degree of chemical stability at atmospheric pressure and at tempratures upto about 100°c.

# Ch - 04 Dielectric Materials

## Introduction

The materials which are used for storing of electrical energy are classified as dielectric materials. Dielectric materials are essentially insulating materials but the functions are different.

## Dielectric constant or permittivity

→ Consider two insulated conducting plates forming capacitor having air in between them. Let the value of capacitance be $C_0$.

→ If a piece of another dielectric, say glass is introduced in the space between the two plates it is observed that the value of the capacitance increases. Let the value of the capacitance be C.

→ The ratio of the capacitance using a material as the dielectric to the capacitance when air is substituted for the material is called permittivity or dielectric constant of that material.

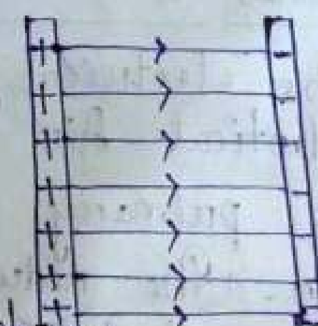
→ The dielectric constant of air is practically taken as 1. permittivities of dielectric other than air are more than 1.

## polarisation

→ polarisation is defined as definite orientation of electrostatic dipoles in a material due to an applied electric field.

→ Consider the two conducting plates of a capacitor. When the capacitor is charged a definite potential will exist between the two capacitor plates.

→ when dielectric is introduced between two plates the intensity of electric field & potential difference between two charged plates is reduced.



→ This is due to polarisation of the dielectric material under the influence of electric field.

→ The better is the dielectric material, the more will be the effect of polarisation.

→ As the voltage drop between two charged plates reduces due to the introduction of dielectric material, the charge storing capacity of the capacitor increases.

Dielectric loss

→ In case of electronic polarisation the electrons undergo only very little displacement and remain within the limits of their atom or ions.

→ Electronic polarisation is set up within extremely small time.

→ Electron displacement in this type of polarisation is elastic in nature.

→ when the polarising field is withdrawn the electrons return to their original position. Ionic polarisation will give rise to only reactive current and there will be no active dielectric power loss involved.

→ In case of polar dielectric the orientation of the dipoles in the electric field is not a pure elastic displacement process. It involves overcoming of certain internal friction forces on which certain amount of energy is expended. This amount of energy is irreversible and is wasted as heat in the dielectric. This wastage of energy is dielectric Loss.

Electrical conductivity of dielectrics and their breakdown

Gaseous dielectrics

→ The electrical conductivity of all gaseous dielectric is identical. Air is most commonly used gaseous dielectric

→ The primary constituent of air are nitrogen & oxygen. The natural ionization gives rise to equal no. of free electrons & positive charge appearing at the same time.

The natural ionizing factors are unable to ionize all the air molecules because ionization of new molecules is counterbalanced by recombination of

Previously formed ion with free electrons.

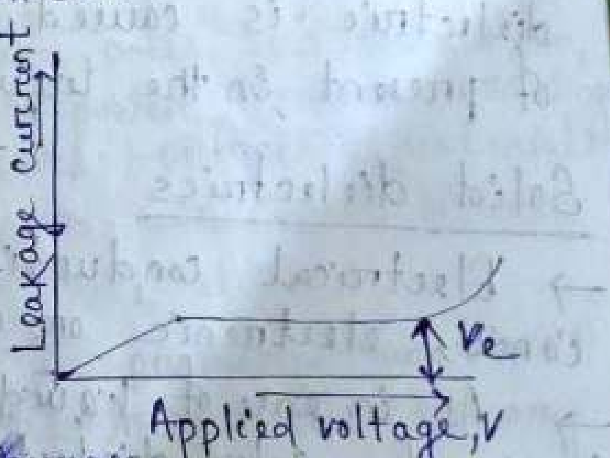
→ Under the influence of electric field, the free charges get a directed motion and give rise to electric current which is known as leakage current.

→ Free electrons will move towards the positive plate whereas positive ion will be attracted towards negative plate.

→ If the applied electric field is mild the random motion of the free charge will be predominant over their directed motion due to applied field.

→ If the electric field is further increased all the free charges will be directed towards the two plates before they can be recombined.

→ If the voltage applied in increased further the free charges will acquire sufficient energy to knock out electrons from other neutral atoms by collision.




→ Each newly freed electron gets accelerated to a very high speed due to applied electric field and this in turn knock out an electron from other gas atom and ionizes them. This process is ionization by collision.

→ The voltage at which a sudden increase in leakage current takes place in a gaseous dielectric is called breakdown voltage.

## Liquid dielectrics

→ All the liquid dielectrics get contaminated with some impurities in the form of solid particles which become suspended in such dielectrics.

→ Another contaminants in hygroscopic liquid dielectric is water.

→ In all commercial liquid dielectric the impurities conductivity plays a very significant role.

→ The basic molecules of dielectric gets dissociated under the influence of electric field. Dissociation of molecules causes conductivity.

→ Contaminants in liquid dielectric can increase the conductivity under the action of electric field.

→ When the dielectric is placed in an electric field, the contaminants become electrically charged and may act as current carriers.

→ A breakdown in a contaminated liquid dielectric may occurs due to formation of conductive bridges between the electrodes by the contaminants drawn into the interelectrode space by the applied electric field.

→ In an uncontaminated liquid such conductive bridges cannot be formed. Breakdown of uncontaminated liquid dielectric is caused due to the ionization of the gases of present in the liquid.

<u>Solid dielectrics</u>

→ Electrical conductivity of solid dielectrics may be ionic, electronic or combined.

→ As in case of liquid dielectric, the electrical conductivity of solid dielectric also depends upon the presence of various contaminants or impurities. In most dielectric these impurities dissociate more readily to form ions & free electrons than the dielectric containing them.

→ Breakdown in solid dielectric may be either electro thermal or electrical depending upon the prevailing conditions.

→ Electrothermal breakdown is caused by the destruction of the dielectric due to heating produced by dielectric losses.

→ Dielectric losses in these dielectric increases very sharply with increase in temperature.

→ If the heat generated is not conducted away rapidly through the dielectric then there will be thermal breakdown of the dielectric.

→ The most probable mechanism of electric breakdown in many solids particularly crystals is collision ionization by electrons.

→ When the applied electric field accelerates the free electrons in the dielectric the electrons lose part of their kinetic energy through collision with the particles in the dielectric which are torn away from the place of their fixing.

# Ch-05 Magnetic Materials

## Introduction

→ Materials which can be magnetized are called magnetic materials. when magnetized they create magnetic field around them.

→ The property of the material by virtue of which it allows itself to be magnetized is called permeability.

→ The permeability of free space is denoted by $\mu_0$ and equals $4\pi \times 10^{-7}$.

→ For magnetic materials $\mu$ is given by

$$\mu = \mu_0 \times \mu_r$$

$\mu_r$ → is called relative permeability

19.08.20

→ In free space, the magnetic flux density(B) is related to intensity of magnetization H

$$B = \mu_0 H$$

→ If the same magnetic intensity (H) which was applied in free space is now applied in a solid, the magnetic flux density is given by

$$B = \mu H$$

It can also be written as

$B = \mu_0(H + M)$

M is called magnetization of the solid. It is resulted from alignment of magnetic dipoles of the material parallel to the applied field intensity. Magnetization is proportional to applied field

$M \propto H$

$\Rightarrow M = \chi H$

$\chi$ is called susceptibility.

putting the value of M in expression of B

$$B = \mu_0(H + \chi H) = \mu_0 H(1+\chi) = \mu_0 \mu_r H$$

where $\mu_r = (1+\chi)$ is called relative permeability.

## Classification

Materials are classified into Diamagnetic, paramagnetic & ferromagnetic materials depending upon the manner in which they respond to external magnetic field.

## Diamagnetism

→ Materials which lack permanent magnetic dipoles are called Diamagnetic.

→ If an external magnetic field is applied to a diamagnetic material it induces magnetization M in the opposite direction to the applied field intensity H.

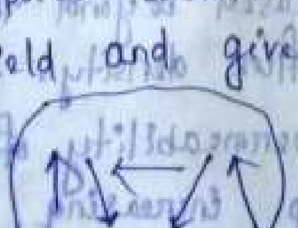
→ Relative permeability of diamagnetic material is negative

## Paramagnetism

→ Many materials have small but positive relative permeability. Such materials are called paramagnetic.

→ In such materials the individual atomic dipoles are oriented in a random fashion.

→ when external magnetic field is applied the permanent magnetic dipoles orient themselves parallel to the applied magnetic field and give rise to positive magnetization M.



## Ferromagnetism

→ Ferromagnetic materials are generally crystalline solids.

→ The permanent atomic dipoles are align parallel to each other within groups called domains.

→ In unmagnetized state, the various domains within a material as a whole have zero magnetization.

→ When a weak external magnetic field is applied, it is not enough to cause any change in the orientation of the domains.

→ When the externally applied magnetic field is increased, the domain will start orienting themselves such that their resultant magnetic field coincides with externally applied magnetic field.

→ There are some domains whose original magnetic orientation greatly diverges from that of the applied field and require stronger external field.

→ Rate of strengthening of the internal magnetic field decreases with increase in the applied magnetic field and ultimately gives rise to state of magnetic saturation

20.08.20

## Magnetisation curve

→ With very weak external applied field, the flux density B rises in direct proportion.

→ During this region upto point x, the domain of the ferromagnetic material donot orient themselves parallel to the applied field.

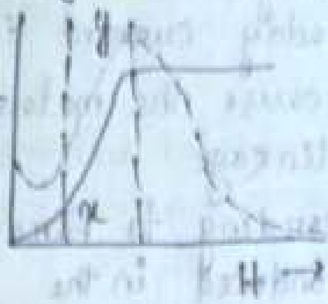
→ Thus the permeability of the material upto the point x is constant called initial permeability.

→ If the external field is increased beyond the point x there is a sharp increase in flux density.

→ Upto the point y, relative permeability of the material is no longer constant but keep increasing.

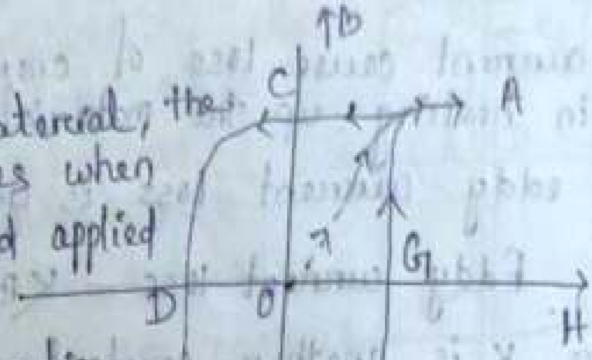
→ when the point y is reached the increase in flux density is slow with further increase in external magnetic field

→ The permeability of the material after the point y starts decreasing.




→ when the magnetization curve reaches point y the material is said to start saturating.

## Hysteresis




→ In ferromagnetic material, the flux density increases when external magnetic field applied to it is increased.

→ If the external magnetic field is reduced, the original curve OA is not retraced.

→ At H equal to zero. the material is still magnetised and the flux density has the value OC. This is called remnant flux density or residual magnetism.

→ In order to demagnetise the material completely, H must be reversed and when it reaches the value OD in the reverse direction, B is now zero.

→ The applied magnetizing force H in the reverse direction which causes B to zero is called coercive force.

→ Further increase of H in the reverse direction will now increase B in the reverse direction and again at E saturation occurs.

→ The residual magnetism in the reverse direction is represented by OF and to neutralise this, H must be increased to the value OG in the positive direction.

→ Further increase of H in the positive direction will again magnetize the material in this direction and saturation occurs at A.

→ The graph relating B & H traces a loop ACDEFGA is called Hysteresis loop.

Eddy current 25.08.20

→ Magnetic materials placed in a alternating magnetic field have eddy current induced in them.

→ Because the material is subjected to rate of change of flux linkage

→ According to Faraday's law of electromagnetic induction emf induced in the material causes current, called eddy current

→ This current cause loss of energy ($I^2R$ loss) which results in heating up the material.

→ The eddy current loss is given by

$$\text{Eddy current loss} = K B_m^2 f^2 t^2 V_e \text{ watt}$$

where K is another constant which depends upon the core material and t is the thickness of core lamination.

→ Eddy current loss is proportional to the square of the frequency and the square of the thickness of the material and inversely proportional to resistivity of the material.

Curie point

→ There is a critical temp. called curie point above which the ferromagnetic material lose their magnetic properties.

→ Above the curie temp. the domain structure tends to disrupt and the domain loss their alignment, becomes arranged in a random fashion. thus the material loss its ferromagnetic property.

Magnetostriction

→ when ferromagnetic materials are magnetized a small change of dimension of the material takes place.

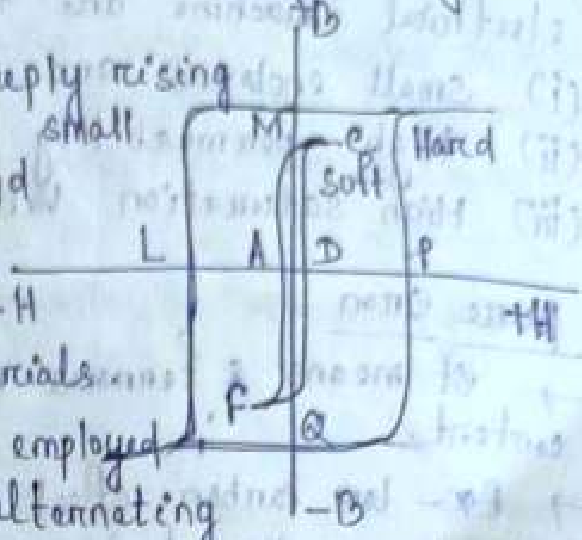
→ There is a small extension with corresponding reduction of cross section of the crystals of which the material is made.

→ When subject to rapidly alternating magnetic field there is a rapid and continuous extension & contraction of the material. This is called magnetostriction.

## Soft and hard magnetic materials

→ All ferromagnetic materials may be divided into two broad groups (a) soft magnetic materials (b) hard magnetic materials.

→ Materials which have a steeply rising magnetization curve, relatively small and narrow hysteresis loop and consequently small energy loss during cyclic magnetization are called soft magnetic materials.




→ Soft magnetic materials are employed in building cores for use in alternating magnetic field.

→ Ex- soft iron, nickel-iron alloys and soft ferrites.

→ Magnetic materials which have gradually rising magnetization curve, large hysteresis loop and consequently large energy loss.

→ These are used for making permanent magnet.

→ Ex- carbon steel, tungsten steel, cobalt steel, alnico, hard ferrites.

26.08.20

## Soft magnetic material

→ Soft magnetic materials are used for construction of cores for electrical machine, transformers, electromagnets, reactors, relay etc.

→ The construction of equipment demands that the magnetic flux should be produced in minimum space and with minm loss.

→ $\phi = B \times A$, To obtain a given value of flux, a high value of flux density to keep the minimum c/s area means less quantity of material.

→ A value of flux density above saturation should not be chosen as it will give rise to large magnetizing current.
→ while choosing the flux density for a given application the amount of magnetic material used and iron losses are kept as low as possible.
→ The requirement for magnetic material for use in electrical machine are transformers are
(i) small enclosed area of hysteresis loop
(ii) High permeability
(iii) High saturation value of flux density

pure iron

→ It means a ferrous material with an extra low carbon content.
→ Ex – low carbon steel & electrolytic iron.
→ In low carbon steel carbon content is less than 0.1 percent
→ The resistivity of pure iron is low by virtue of which it give rise to large eddy current loss when operated at high flux density.
→ Technically pure iron is widely used in many kinds of electrical apparatus and instruments as magnetic material core for electromagnets, components for relay electrical instruments.

Iron-silicon alloys

→ By incorporating small quantities of other elements in iron good magnetic properties are obtained.
→ The chief alloying constituent is silicon which is added to iron in amount from about 0.5 to 5 percent by weight.
→ Extensive use is made of iron-silicon alloy usually called silicon steel for relatively strong alternating magnetic field generally used in transformers, electrical rotating machine, reactors, electromagnets & relays.

Nickel iron alloy 27.08.20

→ Iron & Iron-silicon alloys have low initial permeability.

→ For high sensitivity & low distortion needed in communication systems, the iron-silicon alloys are not suitable.

→ Special magnetic alloys having initial and maximum permeability are used for special application like instrument transformers, relay etc.

→ A group of iron alloys containing nickel between 30 to 80 percent with possible addition of molybdenum & chromium show very high permeabilities at low flux densities & much lower losses than iron.

→ The important alloys are permalloy, supermalloy & Mumetal.

Soft ferrites

→ Ceramic magnets also called ferromagnetic ceramics and ferrites are made of an iron oxide $Fe_2O_3$ with one or more divalent oxides such as NiO, MnO or ZnO.

→ These magnets have a square hysteresis loop and high resistance to demagnetization.

→ The advantage of ferrites is their high resistivity.

→ Ferrites are carefully made by mixing powder oxides, compacting and sintering at high temp.

→ High freq. transformer in television and freq. modulated receivers are almost always made with ferrite cores.

→ In high frequency application magnetostriction in ferrites can lead to undesirable noise.

Hard magnetic materials

→ Hard magnetic materials are used for making permanent magnet. The desired properties of material required of making permanent magnets are high saturation values, high coercive force and high residual magnetism.

01.09.20

Carbon steel, tungsten steel, cobalt steel

→ soft magnetic materials cannot be used for making permanent magnet because they have narrow hysteresis loop.

→ when cabon is added in a material its hysteresis loop area is increased.

→ Although carbon is cheap but magnets made from carbon steel loss their magnetic properties very fast under the influence of knocks & vibration.

→ when materials like tungsten, chromium or cobalt are added to carbon steel its magnetic properties are improved.

Alnico

→ Alloys like ALNICO (Aluminium - nickel - iron cobalt) are commercially the most important of the hard magnetic materials.

→ As compared to cobalt steel it is cheaper.

→ Alnico is an exceptionally hard magnetic material and due to this reason now a days permanent magnets are most commonly made of Alnico.

Hard ferrites

→ Hard magnetic ferrites like $BaO(Fe_2O_3)_6$ are used for manufacture of light weight permanent magnet due to their low specific weight

## Ch-06 Materials for special purposes

**Introduction**

→ Some materials used in electrical engineering application perform secondary function.

→ consider structural materials like poles and towers for distribution and transmission of electric power, frames of rotating machines, frames of electrical heaters, protective materials like lead sheathing and steel armouring on cables, bitumen in cable joint boxes and underground cable etc.

→ These materials donot perform the primary function of the concerned equipment yet without their use primary function would not be accomplished efficiently.

**Structural Materials**

→ cast iron, styl, timber, reinforced concrete are the common materials used for this purpose.

→ Cast iron is used as material for the frames of small and medium sized electrical machines.

→ steel find its use in fabricated frames for large electrical machines, tanks for transformers, fabrication of transmission towers & large no. of other application.

→ Timber & reinforced concrete are commonly used poles for overhead lines.

## Protective materials

Lead: Lead is soft, heavy & bluish grey metal. It is highly resistant to many chemical actions but can corrode by nitric acid, acetic acid, lime & rotten organic substances.

→ The electrical conductivity of lead is 7.8% of that of copper. Lead & its compounds are toxic. As lead is mechanically weak it cannot withstant vibrations at high temperatures.

→ pure lead sheath cable are liable to fail in service due to formation of cracks formed because of vibration.

→ Lead alloyed easily with tin & zinc and form many commercial alloys including solder & bearing metal.

## Steel tapes, wires & strips

→ steel tapes, wires and strips are commonly used as protective material for mining cables, underground cables, weather proof cables etc.

## Bitumens

→ Bitumens are used for protection against corrosion.

## Other materials

## Thermocouple materials

→ when two wires of different metals are joined together an emf exists across the junction which is dependent upon type of metal or alloy used and also directly proportional to the temperature of the junction.

→ when one tries to measure this emf more junctions are to be made. which will also give rise to emf.

→ when all the junction are at the same temp. the resultant emf will not be zero.

→ The emf produced by thermocouple is very small but it can be measured with reasonable accuracy by sensitive moving coil millivoltmeter.

→ Depending upon the range of temperature to be measured, proper materials are to be chosen for a thermocouple.

## Bimetals

→ A bimetal is made of two metallic strips of unlike metal alloys with different coefficient of thermal expansion.

→ At a certain temperature the strip will bend & actuate a switch or lever of a switch.

→ The bimetal can be heated directly or indirectly. When heated the element bends so that the metal with greater coefficient of expansion is on the outside of the arc formed while that with smaller coefficient is on the inside.

→ When cooled element bends in the other direction.

→ Bimetallic strips are used in electrical apparatus and in devices such as relays & regulators.

→ A bimetal relay or release can be used for overload protection of electric motor or any electric circuit. In such an arrangement the circuit current is passed through the bimetallic strip. If the current rises above its setting the strip will be heated enough to bend & break the circuit directly or through an intermediate relay.

## Soldering Materials

→ An alloy of two or more metals of low melting point used for base metal is known as soldering. The alloy used for joining the metals is called solder.

→ Many commercial solder contain larger percentage of lead & antimony with less tin.

→ For proper soldering flux is to be used. In soldering process the application of flux serves to remove oxides from the surface to be soldered.

→ For ordinary soldering, zinc chloride is the common flux. Solders are of two types; soft solders and hard solders.

→ Soft solders are composed of lead & tin in various proportions. common hard solders are silver solders, aluminium solders, copper-zinc solders etc

→ Aluminium can not be soldered using conventional solders & fluxes in view of extreamly tough ~~surface~~ oxide film present on the surface of Aluminium.

→ London associate's Fry's metal foundries developed a suitable solder and flux for the jointing of Al and as a result Alca P solder was developed.

→ EYRE No.7 flux is an improved variety of organic flux which is used with Alca P for Aluminium cable jointing

## Fuse & Fuse material

→ A fuse is a protective device which consist of thin wire or strip. The wire or strip is placed with the circuit it has to protect, so that circuit current flows through it.

→ when this current is too large, the temp. of the wire or strip will increase till the wire or strip melts thus breaking the circuit and interrupting the supply.

→ The current is cut off by the fuse like upon melting of the wire the metal ions form an arc and constitute a conducting path through which current continues to flow.

→ In order to quench the arc, the resistance in the arc path must rise to such an extent that the available voltage is no longer able to sustain the arc.

A rewirable fuse is not at all suited to quench an arc properly because any type of wire can be used, no proper cooling of the arc can be provided and no pressure can be built up.

A fuse material should possess the following properties

(a) Low resistivity : This means, thin wires can be used which will give less metal vapour after melting of the wire. Less metal vapour in the arc gives lower conductivity and thus makes quenching of the arc easier.

b) Low conductivity of the metal vapour itself.

(c) Low melting point : This means that the temperature of the fuse material for normal current stays at low value.

→ only lead was used as fuse material because of its low melting point. In catridge fuse silver & silver alloys are used in fuses of lower ratings and copper alloys are used in fuses of higher rating.

→ The rating of any fuse depends entirely on its dimension, mounting, surrounding powders or liquids, enclosure and other factors which affect its heat dissipating capacity & its ability to extinguish arc after fusing.

Dehydrating Material

Silicagel -

→ It is an inorganic chemical, a colloidal, highly absorbent silica used as a dehumidifying and dehydrating agent, as a catalyst carrier and sometimes as catalyst.

→ calcium chloride and silicagel are used in dehydrating breathers to remove moisture from the air entering a transformer as it breathes.

→ silicagel breathers are a more recent developement and are replacing calcium chloride breathers. Its main advantage is that when it becomes saturated with moisture it doesnot restrict breathing as does calcium chloride.

→ silicagel when dry is blue in colour and the colour changes to pale pink as it becomes saturated with moisture. It can be dried by heating it in an open container at a temp. betn 150°C & 200°C.

→ calcium chloride can be dried by heating in the same manner at temp. of between 180°C & 200°C until completely dry.