LECTURE NOTES

ON

ELECTRICAL ENGINEERING MATERIAL

TH-4

DIPLOMA COURSES

3RD SEMESTER

ELECTRICAL ENGINNERING

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Electrical Engineering Materials

CHAPTER-1

Materials which are used in the field of electrical engineering are called electrical engineering materials.

These materials are classified based on their properties and applications are as follows.

- Conducting materials
- Insulating materials
- Semiconductor materials
- Magnetic materials
- Dielectric materials
- Special purpose materials

Conducting materials :-

Materials which allows electric current to pass through them easily are called conducting materials.

- Almost all pure metals are good conductors of electricity.

Some important conducting materials in order of their conducting ability are.

- silver, copper, Aluminium, Brass, Zinc, Nickel, Iron Tin, lead, German silver, Manganin, Eureka, Nichrome Tungsten, Mercury

Applications:-

- House wiring
- Winding of electrical machines
- Transmission & distribution lines.

Insulating materials:-

- Materials which prevents electric current to pass through them are called insulating materials.
- Examples are Rubber, PVC, Plastic, cotton

Applications:-

- To isolate the live conductors in all applications from earth or body
- To isolate the winding from the body in all electrical machines.

Semi-conducting materials:-

- Materials which have a conductivity between conductor & insulater are called semi-conducting materials.
- Examples are Germanium, silicon

Applications:-

- In rectifiers & control circuits
- In electronic circuits
- In photo-conductive & photovoltaic cell.

Dielectric materials:-

- A dielectric material is a substance which is a poor conductor of electricity but an efficient supporter of electrostatic fields.
- The dielectric materials are used to store electrical energy.
- Examples are Mica, Paper

Applications:-

- In capacitors.

Magnetic materials:-

- Materials which provide path for the mag flux are called magnetic materials.
- Examples are Iron, cobalt, steel etc

Applications:-

- Used in making magnetic circuits.
- Used in electromagnetic machines, relays & transformers.

Special purpose materials:-

- Materials used for specific type of applica purposes like safety, protective and relaying.
- Examples are fuse, soldering materials et

Applications:-

- House wiring
- Electronic circuits
- Switchgear and protection

Resistivity:-

The resistivity of a substance is the resistance of a cube of that substance having edges of unit length, with the understanding that the current flows normal to opposite faces & is distributed uniformly over them.

The electrical resistivity is the electrical resistance per unit length & per unit of cross-sectional area at a specified temperature.

- The SI unit of electrical resistivity is the ohm meter (Ωm) which is commonly represented by the Greek letter ρ (rho)

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

$$\rho = \frac{Ra}{l}$$

Where R is the electrical resistance of a uniform specimen of the material measured in ohms.

l is the length of the piece of material measured in metres, m

A is the cross-sectional area of the specimen measured in square-metres, m^2.

(5) Factors affecting the resistivity of electrical materials

Factors affecting the resistivity of electrical materials are listed below

- Temperature
- Alloying
- Mechanical stressing
- Age hardening
- Cold working

Temperature:-

- The resistivity of materials changes with temperature. Resistivity of most of the metals increase with temperature.
- The change in the resistivity of material with change in temperature is given by formula given below

$$\rho t_2 = \rho t_1 [1 + \alpha_1 (t_2 - t_1)]$$

Where ρt_1 is the resistivity of material at temperature of $t_1°C$

ρt_2 is the resistivity of material at temperature of $t_2°C$.

α_1 is the temperature coefficient of resistance of material at temperature of $t_1°C$.

e.g. the impurity of silver (having lowest
resistivity among all metals) in copper increase the resistivity of copper.

Mechanical stressing:-

- Mechanical stressing of the crystal structure of material develops the localized strains in the material crystal structure.
- These localized stains disturb the movement of free electrons through the material which results in an increase in resistivity of the material. subsequently, annealing of metal reduces the resistivity of metal.
- Annealing of metal, relieve the mechanical stressing of material due to which the localized stains get removed from the crystal structure of the metal.
- Due to which the resistivity of metal decrease
- e.g. the resistivity of hard drawn copper is more as compared to annealed copper.

Age hardening:-

- Age hardening is a heat treatment process used to increase the yield strength & to develop the ability in alloys to resist the permanent deformation by external forces.
- Age hardening is also called precipitation hardening. this process increases the strength of alloys by creating solid impurities or percipitate.

(6) If the value of α_1 is positive, the resistivity of material is increase.

- The resistivity of metals increase with increase of temperature means the metals are having positive temperature coefficient of resistance.
- Several metals exhibit the zero resistivity at temperature near to absolute zero. This phenomenon is called superconductivity.
- The resistivity of semiconducter & insulators decrease with increase in temperature means the semiconducters & insulators are having negative temperature coefficient of resistance

Alloying :-

- Alloying is a solid solution of two or more metals. Alloying of metals are used to achieve some mechanical & electrical properties.
- The atomic structure of a solid solution is irregular as compared to pure metals. Due to which the electrical resistivity of the solid solution increases more rapidly with increase of alloy content.
- A small content of impurity may increase the resistivity metal considerably even the impurity of low resistivity increases the resistivity of base metal considerably.

- These created solid impurities or percipitate, disturb the crystal structure of metal which interrupts the flow of free electrons through metal / Due to which the resistivity of metal increases.

Cold working:-

- Cold working is a manufacturing process used to increase the strength of metals. Cold working is also known as work hardening or strain hardening.
- Cold working is used to increase the mechanical strength of the metal which disturbs the crystal structure of metals which interfere with the movement of electrons in metal due to which the resistivity of metal increases.

(a) Classification of conducting materials :-

The conducting materials are classified into two types.

- Low resistivity materials
- High resistivity materials.

Low resistivity materials:-

Low resistivity materials are used in house wiring, as conductor for power transmission & distribution, in the windings of transformer & machines like motors & generators.

- Low resistivity materials are used in all such applications where Power loss & voltage drop should be low.

A low resistivity material, besides possessing low value of resistivity should also possess the following additional properties

a) Low temperature coefficient

b) Sufficient mechanical strength

c) Ductility

d) solderability

e) Resistance to corrosion.

Low resistivity materials & their applications:-

Copper:-

Properties of copper:-

- It is the 2nd best conductor of electricity.
- It's conductivity is approximately 100%.
- Its resistivity is little higher than silver.
- It is raddish-brown in colour
- It is non-magnetic & ductile in nature.
- It is highly resistant to corrosion.
- It can be welded at red heat & low contact resistance
- Annealed copper is soft in nature, less tensile strength & high conductivity than hard drawn copper.
- Hard drawn copper has low conductivity than annealed copper & has high mechanical strength.

Application:-

→ Copper is used for making wires of cables for transmission & distribution of electric power & for motor & generator windings.

- Copper is also used for high voltage underground cables.
- Rolled copper bars used for making bus-bars.
- Hard drawn copper is used for overhead conductors ~~for~~ because of its high mechanical strength.

(ii)- Annealed copper is used for insulated conductors for low voltage power cables, winding wires for electrical machines & transformers, flexible wire & in making coils for many purposes.

- Copper conductors having steel core are empl for long span transmission lines where high conductivity, small sag & minimum cross section ar desired.

Aluminium:-

properties of Aluminium:-

- Its electrical conductivity is next to copper
- It is soft & silvery coloured metal
- It is malleable & ductile
- It offers high resistance to corrosion
- It forms useful alloys with iron, copper, magnesi & other metals.
- It is cheap & is readily available.

Application:-

- It is used in overhead transmission lines domestic wiring, flexible wires, bus bars, rotor bars of squirrel cage induction motor.
- It is used in overhead transmission lines in the form of A.C.S.R (Aluminium Conductor Steel reinforced) Conductors.

- For making capacitor foils, cable sheaths
- Well suited for cold atmospheric conditions.
- For making almuminium alloys
- Used for electrical conducting wires & cables.
- Used for windings of generaters & transformers.
- Used for overhead conductors & bus bars.

Silver:-

Properties of silver:-

- Pure silver has high electrical conductivity & corrosion resistance.
- In order to make it harder 15% copper is added into it.

Application:-

- It is used in commutator segment of small d.c. motors as alloy of silver- copper containing 90% copper is used.
- For brushes & collector ring of d.c. motors silver graphite alloy. containing a small percentage of graphite is used.

Gold:-

- Gold is the best electrical conductor
- It is found in the form of dust in the beds of rivers.
- It is malleable & ductile & can be easily beaten into translucent sheets.

Application:-

- It is largely used as alloy to make coins & jewellery.
- Its good corrosion resistance property makes its alloy very much useful as contact material in electrical field.
- Its alloy is also used ~~for~~ as corrosive resister brazing material

Steel:-

Properties of 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.

- Therefore, if the carbon content is too high ~~the~~ the steel is brittle.

Application :-

- Zinc coating steel (Galvanised steel) wires are used as over head telephone wires & as earth wires.

Stranded conducters:-

- Stranded conducters are made by twisting the thin wires of smaller cross-section. Wires of each layer are then laid helically around the wires of other layer.
- This process is called stranding which is done in opposite directions for successive layers i.e. if the wires of one layer are twisted clockwise direction then the wires of next layer are twisted in anticlockwise direction.

Application:

- Circular stranded conductors are used for 3-ϕ applications & in making core cables.

Bundle conducters:-

- A bundle conducter is a conducter made up of two or more conducters called the sub-conductor per phase in close proximity compared with the spacing between phases.

(15) It has several advantages such as (6)

- Reduced Corona loss & radio interference
- Reduced losses thereby giving higher transmission efficiency
- Higher charging current.

Low resistivity copper alloys:-

Brass:- When copper is alloyed with zinc (60% copper, 40% zinc), it is called brass which has high tensile strength but has lower conductivity than copper.

Application:-

- It is used as a current carrying & structural materials in plug points, socket outlets, switches, lamp holders, fuse holders, knife switches, sliding contacts for starters & rheostats etc.

Bronze:- copper when alloyed with tin (8% to 16%) & a third element like cadmium, Beryllium, Phosphorus, Silicon etc. is called Bronze.

Application:-

- Cadmium bronze is used for contacting conductor & Commutator segments, beryllium bronze is used for making current carrying springs, sliding contacts, knife switch blades etc.

Beryllium copper alloys:-

Copper alloy containing beryllium is also called bronze

Application:-

- used for making current carrying springs, brush holder, bellows, Coil springs, sliding contacts & knife switches.

Lecture-4

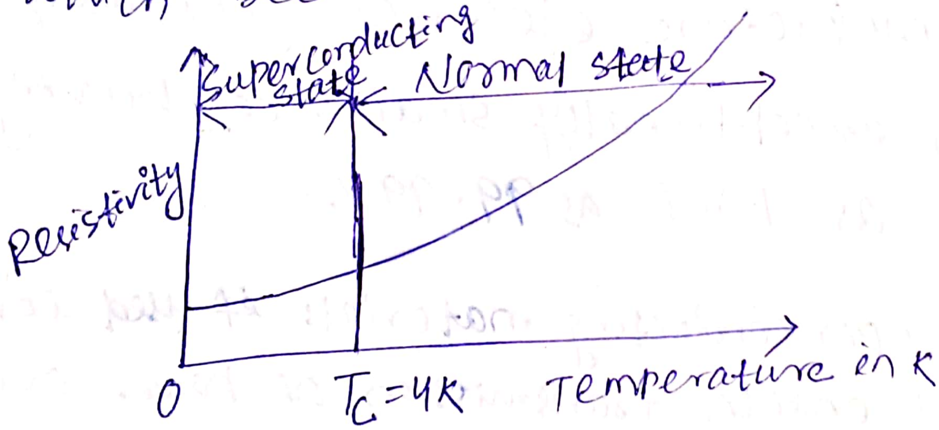
Subject :- EEM
Semester :- 3rd

Superconductivity:-

The property or phenomenon of infinite conductivity in materials is called superconductivity.

→ The temperature at which the metals change from normal conducting state to superconducting state is called critical temperature/transition temperature.

→ An example of superconductor is Mercury which becomes superconductor at 4K.



Superconductor Metals:-

Some Metals when they are cooled below their critical temperature exhibits the zero resistivity or infinite conductivity. These metals are called superconductor metals.

e.g.

e.g.	Rhodium (Rh)	$T_c \rightarrow 0'$
	Tungsten (W)	0.015
	Beryllium (Be)	0.026
	Iridium (Ir)	0.1

Properties of superconductors:-

1. Zero electric resistance (infinite conductivity.
2. Expulsion of magnetic field.
3. Critical temperature / transition temperature
4. Critical magnetic field
5. Critical current.

Application of superconductor materials:-

1. Electrical machines:- If we use superconducto as conducting materials, in addition to supercondu magnets which are already being produced, it possible to manufacture electrical generators & transformers in exceptionally small size, having an efficiency as high as 99.99%.

2. Power cables:- superconducting materials if used for power cables will enable transmission of power over very long distances.

3. Electromagnets:- It has been possible to design electro magnets using superconductivity for use in laboratori & for low temperature devices like the maser.

4. Future prospects:- presently Helium is used to achieve low temperature required for superconducti which is an expensive gas. so efforts are being made to develop compounds which exhibit superconductivity at temperatures possible to be obtained by the more easily available & cheaper hydrogen gas.

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Assignment - 1 Subject - EEM

Chapter - 1 Semester - 3rd

1) Name the conducting material which is generally used in plug points, socket outlets, switches & lamp holders. State the properties this material should possess for such applications.

2) Explain the term resistivity. Mention the factor which affect the value of resistivity.

3) Give examples each of low resistivity & high resistivity materials & mention their application in the field of electrical engineering.

4) Give reasons why copper is used in the windings of electrical machines even though it is expensive.

5) What material is used in a filament lamp? Give reasons, why?

6) State the advantage & disadvantages of Aluminium as compared to copper for use as a conductor of electricity.

7) Of what material are high voltage overhead lines for power transmission made? Give reasons.

(8) Explain why carbon material is used as brushes in electrical machines & varacs. Mention any other application of carbon in the field of electrical engineering.

(9) Explain why conducting materials like copper & aluminium are not used as heater elements.

(10) Explain super conductivity. Does it occur with all metals & alloys? Mention any possible applications of super conductors.

Chapter-11

Semiconducting Materials

Introduction:-

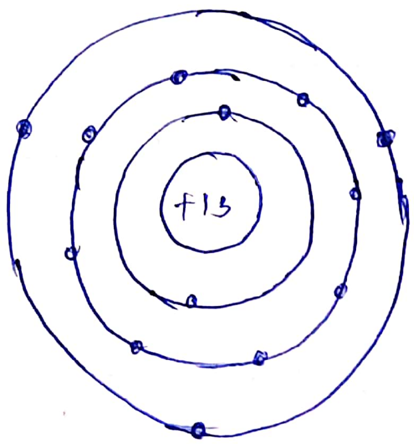
Semiconducting materials have been known for a long time & were indeed used as crystal detectors in the crystal set radio.
- However for many years semiconducters played a minor role in the electronics industry.
While its early application was in pocket radios & hearing aids, today the use of transistors has completely revolutionized the electronics industry, making possible compact computers & satellites.
- Amongst the latest applications of semiconductors is building of integrated circuits in which complete circuit functions are produced in a minute piece of semiconducter.

Semiconducters:-

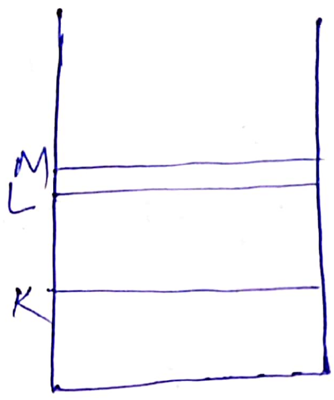
- A semiconducter is neither a good conducter nor a good insulater.
Typical semiconducter materials are Germanium & silicon each of which have four valence electrons.

Electron energy and Energy band theory:-

- According to atomic theory the electrons orbit around the nucleus in various levels or shells.



a) The Bohr Model of an Aluminium 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 whose value is measured in electron volts, commonly expressed as eV.

- 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.

The larger the orbit in which an electron revolves, the greater is its energy, electrons with least energy are on the k level i.e. the orbit closest to the nucleus.

- Each succeeding level contains electrons with higher energy.

Fig.(a) represents the actual energy levels of an alumenium atom: each electron now occupies an energy level different from that of any other, the energy levels have been grouped into energy bands.

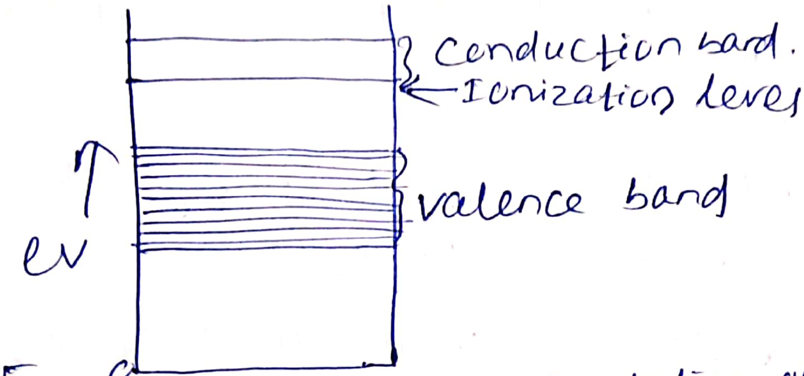
Fig.(b) shows a more general method of representing energy bands. The areas between them are called energy gaps, they are also called forbidden zones since no electron can have an energy represented by these areas.

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 which can be obtained from any of the following sources
Light, heat, Electrostatic, Magnetic, kinetic,

If a required amount of heat energy is absorbed by electron, it will jump to a higher energy level. When the electron is in the higher energy level, the atom is said to be in an excited state.



[Energy band representation of ionization]

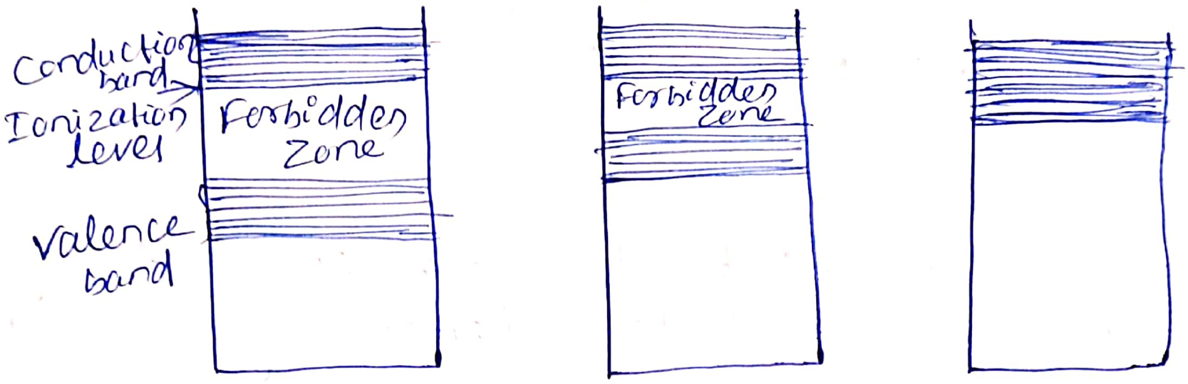
- When the required amount of light or heat energ is absorbed by a valence electron, it will leave the valence band & may move up to ionization lev

- If it does, it is released from the attractive for of the nucleus, then it is free to float around between the atoms & to conduct

- An electron above the ionization level is said to be in conduction band & is called a free electron.

- The ionization level is used because when an electron leaves the valence band, the remaining atom is no longer neutral but has a positive charge & is called a positive ion, the atom is said to be ionized.

Insulators, Semiconductors & conductors:-

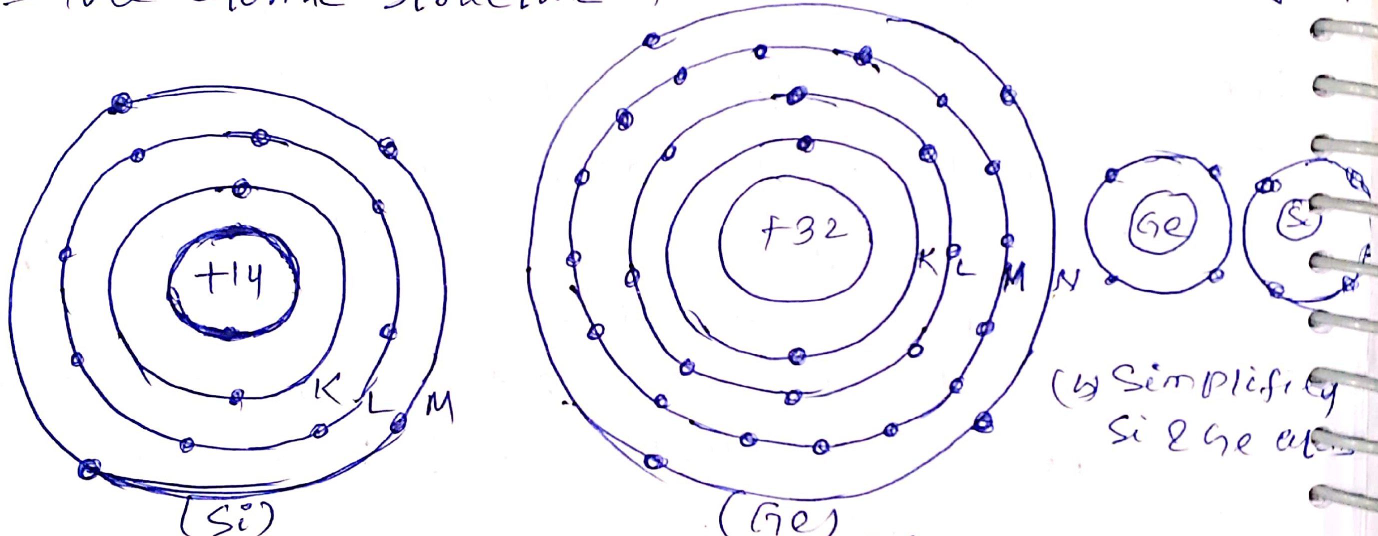


a) Insulater b) Semi-conducter (c) conducter

- Fig(a) shows the ionization level of an insulater in which the forbidden zone between valence band & the conduction band is quite large.
- This indicates that 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.
- Fig (b) shows that in case of semiconductors the forbidden zone is reduced. Thus the valence electrons require less energy to free themselves from the attraction of the nucleus.
- Fig(c) shows that in a conducter there is no gap between the valence band & the conduction band.
- Indeed in the better conductors the conduction & valence bands may even overlap.

Semiconducter materials:-

- The electrical characteristics of semiconducter materials fall between those of insulaters & Conductors.
- Thus a semiconducter has a valence ~~ele~~ ring of four, as compared to valence rings of eight electrons for the best insulaters & one electron for the best conductors.
- The atomic structure of Si & Ge is shown in fig.



(a) Shell Arrangement for Silicon & Germanium

- In Silicon atom K & L shells are full but M shell contains only <u>four</u> electrons.
- According to $2n^2$ formula the M shell can contain 18 electrons however, the M shell in Silicon atom is the valence shell & thus can never contain more than eight electrons.
- In Germanium atom the K, L & M shells are filled & the N shell is the valence shell containing <u>four</u> electrons.

Covalent bonds:-

A covalent bond results when each atom, in order to fill its valence ring with eight electrons, shares electrons or which is called forms covalent bonds, with its neighbouring atoms.

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

However, this structure is not a good insulator for several reasons: First, a good insulator must have a perfect crystal structure. Covalent bonding leads to the development of a polycrystal i.e. several individual crystals held together imperfectly, the extra atoms are not perfectly locked in place & there are missing atoms in some part of the structure.

- Second, due to impurities there may be extra electrons which cannot lock into the covalent bond structure. Impurities can also cause electrons to be missing from the structure.
- Third, energy in the form of heat, light can cause structure disorder.

As a result of the above reasons, the materials does not have a perfect crystal structure

& is therefore not a good insulator but a poor insulator or what is usually called semiconducto

Intrinsic semiconductors:-

- If a crystal (say silicon or germanium) does not contain any impurities atoms i.e. if it contains only one type of atoms, it is called an intrinsic material.
- If its temperature is brought down to $0^\circ K$ (i.e. $-273^\circ C$) 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 temperature above $0^\circ K$, it acts a a conductor.

Extrinsic semiconductors:-

- In order that the material may function prope as a semi-conductor, we must add certian impurities in very carefully controlled quanti
- The addition of impurities is called doping So the material which has been doped (i.e. impurities are added) is called an extrinsi material.

Extrinsic semiconductors are of two types i.e. N-type & P-type.

N-type semiconductor:-

Silicon material is doped with the pentavalent materials like Phosphorus, Arsenic & Antimony.

The loosely bound excess electron which is not required for the bonding easily moves to the conduction band on absorbing small amount of energy.

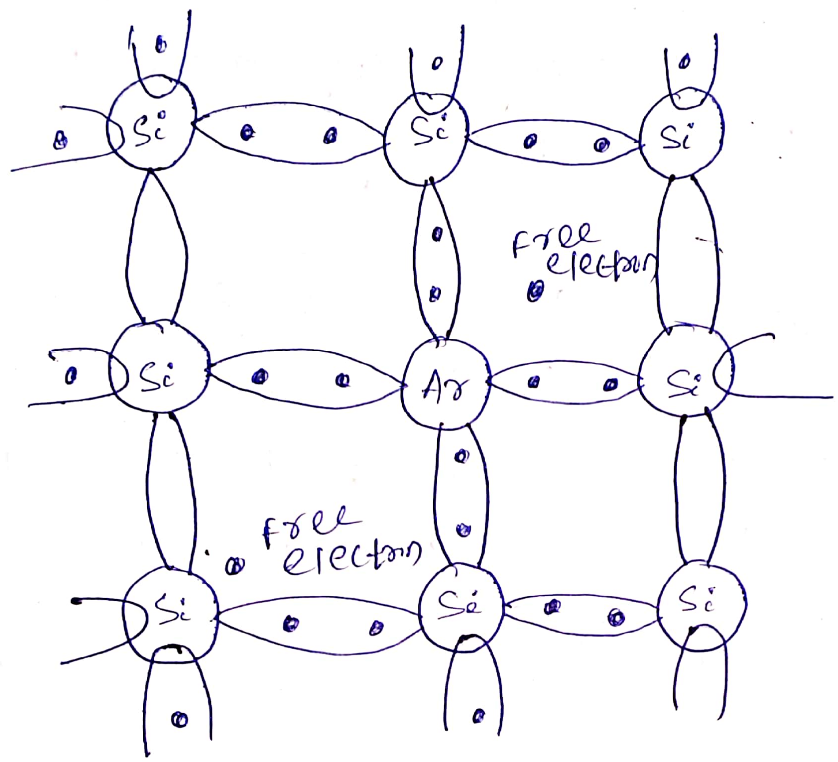
- An impurity atom donates an electron to the conduction band. hence it is a donor atom.
- More free electrons are available in the conduction band than the holes in the valence band - majority charge carriers are negative N-type.
- The free electrons are due to impurity atoms as well as thermal effect - the former effect is dominant.

Conduction in N-type semiconductor:-

When the voltage is applied to the n-type semi-conductor, the free electrons which are readily available due to added impurity, moves in a direction of positive terminal of voltage applied. This constitutes a current.

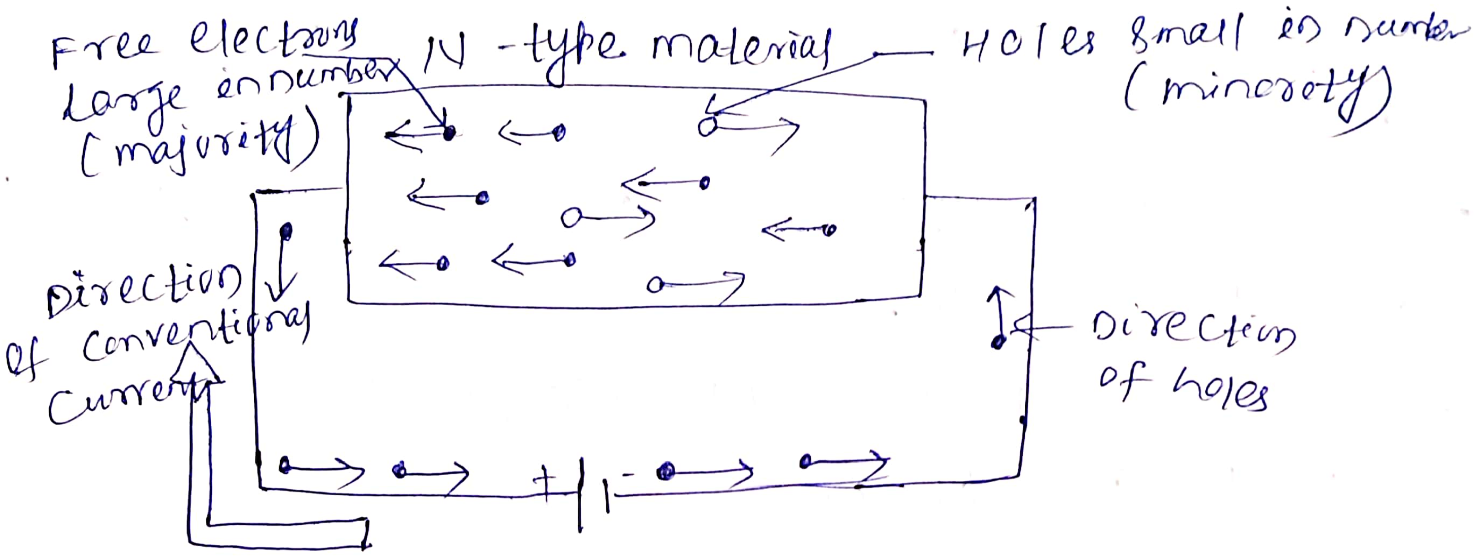
N-type semiconductor:-

- When we add a pentavalent impurity to pure semiconductor we get N-type semiconductor.



[N-type semiconductor]

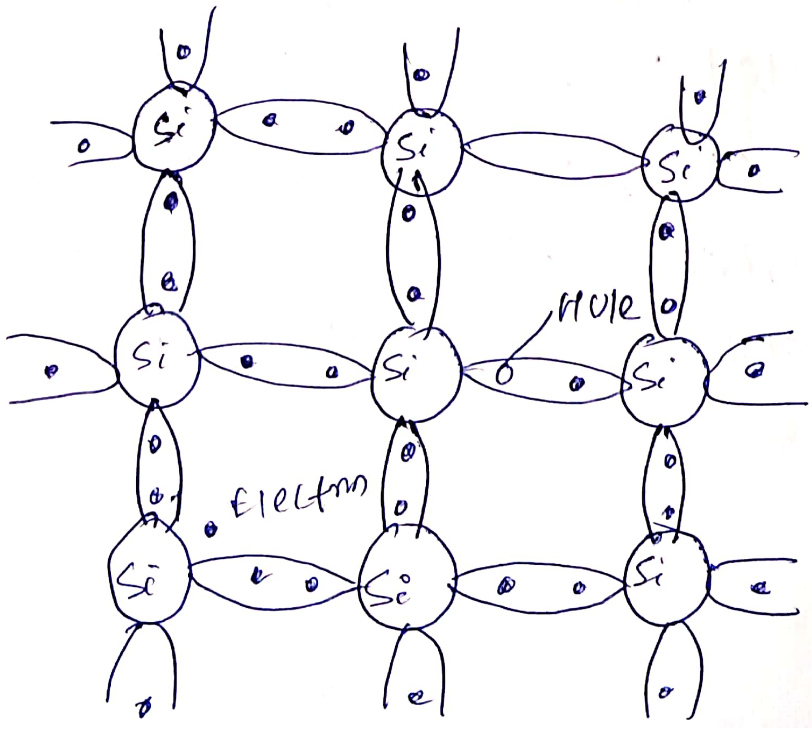
- Arsenic has 5 valence electrons which makes covalent bonds with adjacent four electrons of silicon atom.
- Fifth electron becomes free & enters into conduction band.
- Pentavalent impurity atom donates one electron & become positive doner ion
- Electrons are majority & holes are minority.



The holes are less in number, hence electron current is dominant over the hole current. Hence in n-type semiconductors, free electrons are called majority carriers while the holes which are small in number are called minority carriers.

P-type semiconductor:-

When we add trivalent impurities to pure semiconductor we get p-type semiconductor.

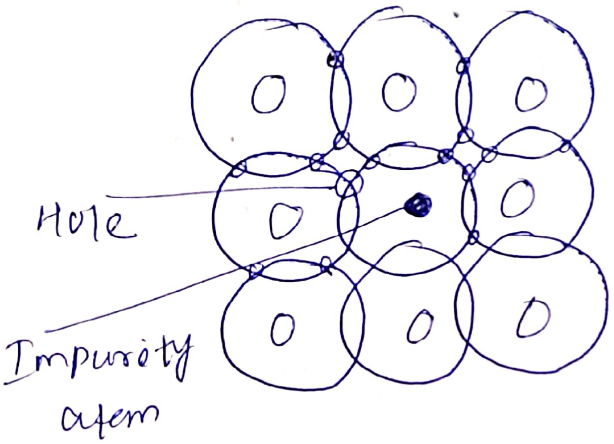


- Gallium atom has three valence electrons which makes covalent bond with adjacent three silicon atoms.
- There is a deficiency of one covalent bond & create a hole.
- Trivalent atoms accept electron which are called accepters.
- Holes are majority carriers & electrons are minority carriers.

Formation & conduction in p-type semiconduc

p-type semiconducter:-

- Trivalent elements like boron & Gallium are added to intrinsic silicon & four covalent bonds are formed around the impurity atom.
- Shortage of one electron in one of the four covalent bonds with the impurity atom is th newly generated hole.
- A impurity atom can accept an electron from a neighbouring atom for the completion of covalent bond & hence the name accepter impurity.

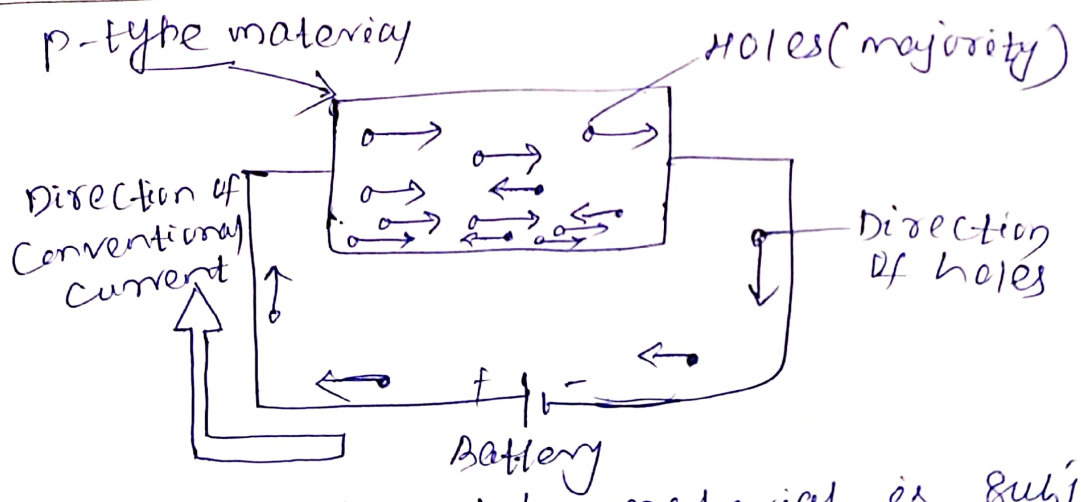


[P-type material]

- The number of holes are equal to the number of impurity atom plus holes due to thermal generation.

Holes are more in number than free electrons & hence they are the majority charge carriers for conduction

Conduction of P-type semiconductor:-



If now such p-type material is subjected to an electric field by applying a voltage then the holes move in a valence band & are mainly responsible for the conduction.

- So the current conduction in p-type material is predominantly due to the holes.
- The free electrons are also present in conduction band but are very less in number. Hence holes are the majority carriers while electrons are minority carriers in p-type material.

Majority & Minority Carriers:-

→ In N-type material, conduction takes place through the electrons created mostly by the doping & a small number created by thermal generation.

→ The small number of holes created by thermal generation move in opposite direction.

So, in N-type material, the number of free electrons is large that electrons are called majority carriers. & holes are in small numbers & are called minority carriers.

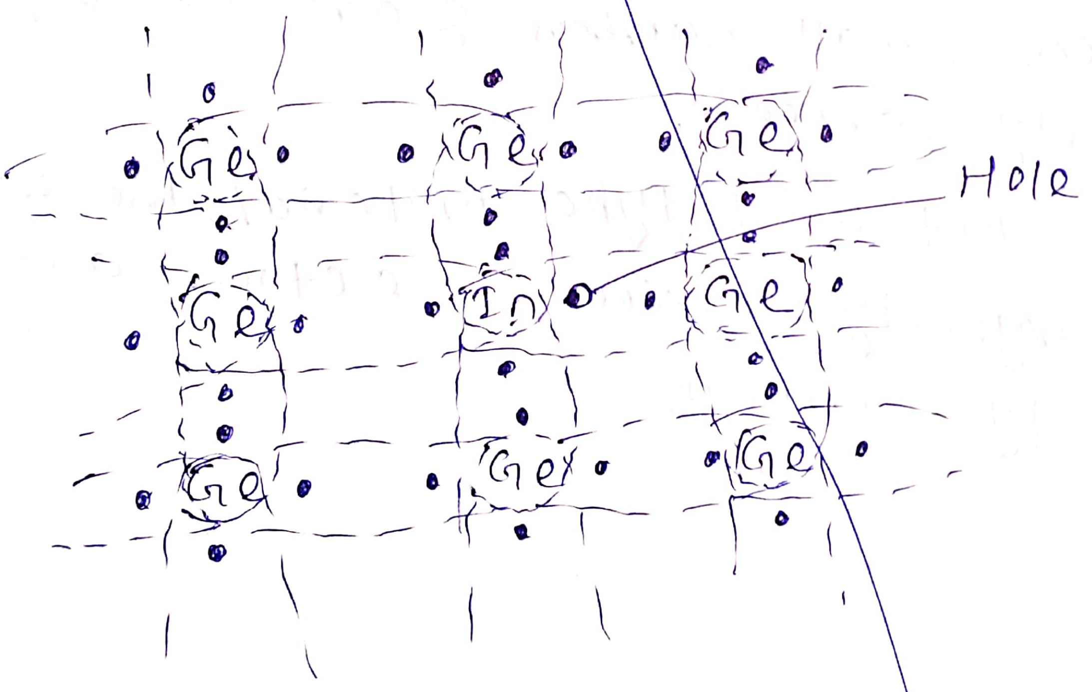
But in P-type material, the holes are majority carries & electrons are minority carriers.

→ Thus, the process will continue creating a mobility of holes & the impurity atom becomes negatively ionized as accepts an electron.

→ The germanium or silicon atom which releases one electron becomes positively ioni

→ The net charge of the material is still neutral, since the total number of protons equals the total number of electron.

So, the intrinsic materials doped with a trivalent impurity are referred to as positive or <u>P-type materials</u>.



Application of semiconducter Materials:-

1) Rectifiers:-

i) Germanium & silicon Rectifiers:-

- Modern P-N junction rectifiers use germanium or silicon as the semiconducter material.
- Modern Silicon combines readily with practically all chemical elements & is therefore very difficult to purify & maintain free from impurity.
- All this world favour the use of germanium. However owing to vital economic & technological advantages especially in heavy current application silicon rectifiers find wider industrial application.

Germanium & silicon semiconducters find wide use in both high frequency & supply frequency circuits particularly as non-controlled rectifiers e.g. diodes & controlled rectifiers.

- Silicon rectifiers can operate upto 200°C. Silicon diodes have an advantage over germanium diodes in high frequency electronic circuits as they are more sensitive to weak signals.
- Silicon rectifiers are normally used in power rectifying devices.

ii) Copper-oxide and selenium Rectifiers:-

- Copper oxide rectifiers are comparatively cheap than silicon rectifiers which are used in rectifier type instruments as in electronic multimeters.
- Selenium rectifier has a greater permissible current density & a wider working temperature range as compared to copper oxide rectifier which find application among other purposes in battery charges & electroplating supplies.
- Both copper oxide & selenium rectifiers are protected against moisture by giving their elements a coating of insulating varnish
- Copper oxide rectifiers completely fail at sufficiently high reverse voltage & selenium rectifiers sometimes self seal, if breakdown occurs at high reverse voltage, by fusion into the amorphous form of selenium which is an insulator.

2) Temperature-sensitive resisters or Thermisters:-

- Increasing the temperature of semiconductor materials causes their resistance to decrease. This property has found application in devices called thermisters.

- Thermisters find application in temperature measurement & control which sense temperature variations & convert these variations into an electrical signal which is then used to control heating devices.
- Other applications of thermisters include measurement of radio frequency, power, voltage regulation & timing & delay circuits.

Photoconductive cells:-

- The resistance of semiconducter material is low under light & increase in darkness which is used in photoconductive cells where a semiconducter material is connected in series with a voltage source.
- Photoconductive cells can be used in applications which require the control of a certian function or event according to the ~~cent~~ colour or intensity of light.
- Some ~~other~~ of their applications are those of door openers, burglar alarms, flame detecters, smoke detecters & control for street lights.

4) Photovoltaic cells:-

- Photovoltaic cells are devices that develop an e.m.f when illuminated which convert light energy directly into electrical energy.

5) Varisters :-

- The resistance of semiconductors varies with the applied voltage. This property is used in devices called varisters
- Use of varisters is made in voltage stabiliz & motor speed control.

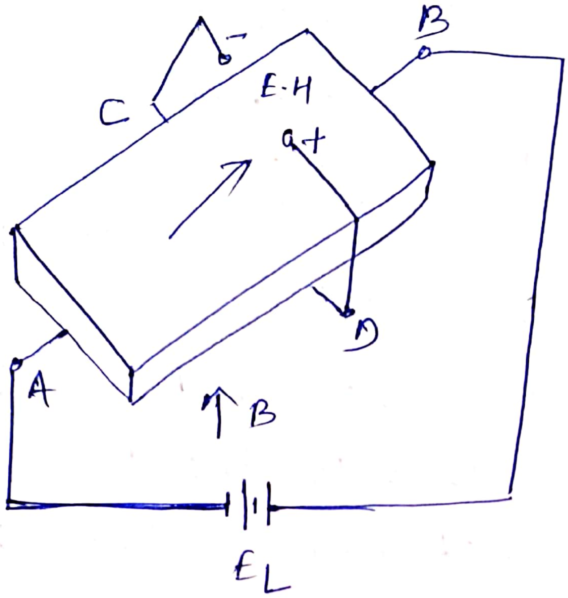
6) Transisters :-

- The resistance of semiconducters depends to a large extent on the magnitude of electric field. The current in a semiconducter does not follow ohm's law & increase far more rapidly than the voltage. This property has been used in the device called transister.
- Transisters have replaced the vacuum & gas tubes in performing many jobs including amplification of signals & switching circuits.

7) Hall effect Generaters :-

- When a current flows through a semiconducte 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 & the intensity of the magnetic field. This is called the hall effect.



Consider the semiconductor bar as shown in fig which has contacts on all four sides.

- If a voltage E_L is applied across the two opposite contacts A & B a current will flow.
- If the bar is placed perpendicular to a magnetic field B, as shown in fig., 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 & can be detected with a simple voltmeter.

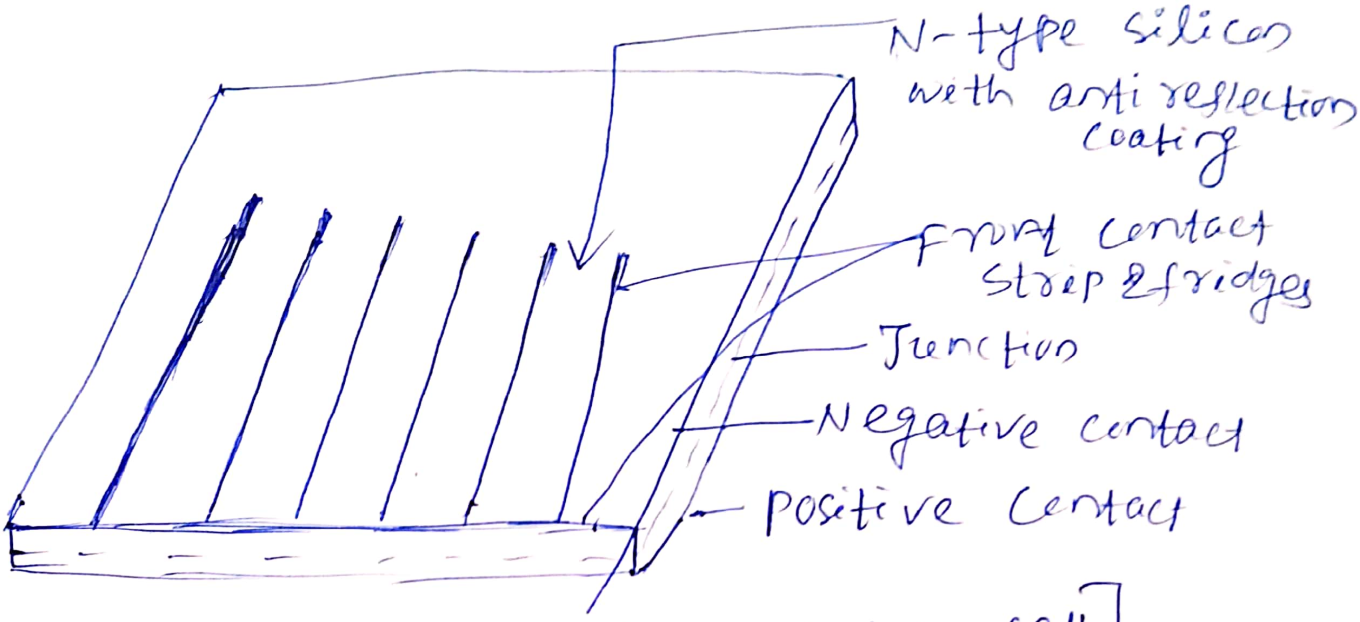
The Hall effect generator may be used to measure magnetic fields which is capable of measuring magnetic field strengths that have a strength

8) Strain gauges:-

- Semiconductors besides being sensitive to heat, light, voltage & magnetic field are also sensitive to mechanical forces
- Silicon & other semiconductor material make very sensitive strain gauges which are devices used to measure small changes in the lengths of solid objects.
- Strain gauges are used extensively by civil engineers to test the tensile strength of materials & in determining the change in the length of structures.

9) Solar power:-

- Sun is a vast source of energy. one of its important applications is the conversion of solar power into electrical power. This phenomenon is called the photo voltaic effect.
- Solar cell is the most important photo voltaic device which directly converts the solar radiation (light energy) into electrical energy.
- The output depends on the intensity of the sun rays. As the cell is turned away from the sun, the output decreases approximately as the cosine of the angle of incidence.



[Top view of a commonly used solar cell]

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

Chapter-III

Insulating Materials

Insulating materials :-

The most important material used in the high voltage apparatus is the insulation.

Insulating materials offers very high resistance to the flow of electric current.

Examples :- Glass, wood, Rubber, paper, P.V.C, Mica.

An ideal insulating material (liquid or solid) must have the following properties

- High insulation resistance
- High breakdown strength
- No absorption for moisture
- Good heat dissipation
- Sufficient mechanical strength to withstand vibration & bending
- Capable of withstanding a repeated heat cycle without deterioration.

Types of insulating materials:-

Types of insulating materials are

- Solids
- liquids
- Gaseous

Solid insulating materials:-

- Solid insulating materials are used in all kinds of electrical circuits & devices to insulate one current carrying part from another when they operate at different voltages
- Solid insulating materials have higher breakdown strength compared to liquids & gases.

Ex:- Glass, wood, Mica, Rubber, Fiber, paper, PVC

Liquid insulating materials:-

- Liquid insulating materials normally are mixture of hydrocarbons & are weakly polarized.
- Liquid insulating materials are more useful as insulating materials than either solids or gases because of their inherent properties

Ex- Petroleum oils, synthetic hydrocarbons, Halogenated hydrocarbons, silicon oils, Askarel, Fluorocarbons, organic esters including castor oils.

Gas insulating materials:-

- Air at atmospheric pressure is the most common gaseous insulation.
- High pressure gas provides a flexible & reliable medium for high voltage insulation.

Ex:- Air, Nitrogen(N_2), carbon dioxide(CO_2), Freon(CCl_2F_2), Sulphur hexa floride(SF_6).

Properties of insulating materials:-

The most important properties for the selection of good insulating materials are

i) Electrical properties
ii) Mechanical "
iii) Thermal "
iv) Chemical "
v) visual "

i) Electrical properties:-

The primary function of an insulating material is electrical & hence electrical properties are of utmost importance.

The various electrical properties are given below

- Insulation resistance.
- Dielectric strength
- Dielectric loss

Insulation resistance:-

It is the property of an insulating material by virtue of which it opposes the flow of electric current.

For an insulating material its value should be as high as possible.

- If a voltage V volts is applied to an insulator, when I ampere of current is flowing through it, then the insulation resistance R in Ω is given by $R = \frac{V}{I}$.

- Insulation resistance is categorized into two types
  - Volume resistance
  - Surface "

Volume resistance:-

- It is the resistance offered to the current I, which flow through unit cube of a material, is measured in Ω-m or Ω-cm

$$\text{Volume resistance} (R_V) = \rho_V \frac{l}{a}$$

Where ρ_V = Volume resistivity in Ω-m

l = Length of current path through the material in m

a = The area of cross section of the current path in m^2

Surface resistance:-

- It is the resistance offered to the current I, which flows over the surface of the insulating material
- Surface resistivity is normally equal to the resistance of a unit square over the surface of the insulating material, is expressed in Ω/sq-cm or Ω/sq-m

Factors affecting insulation resistance:-

Temperature:- Insulation resistance decreases with the rise of temperature & is very much affected by temperature variations.

Moisture:- Surface resistance of the insulation decreases if exposed to moisture & causes insulation breakdown

Voltage:- Insulation resistance decreases with the increase in applied voltage

Age:- As the insulation serves for long years its resistance will decrease with the age of service

Applications:-

Insulating materials are used as a insulation medium in Transformers, Motors, Generators, Cables.

Dielectric strength:-

- Dielectric strength (or electric strength or breakdown voltage) is the minimum voltage which when applied to an insulating material will result in the destruction of its insulating properties

or

Dielectric strength of an insulating material is the maximum potential gradient that the material can withstand without rupture

- Dielectric strength for different insulating materials

Material	Dielectric Strength (Kilo-Volts/mm)
Natural Rubber	24
Synthetic "	4.0 – 36
Asbestos (Paper based laminates)	3.5 – 4
Mica	80
High voltage procelain	10 – 16
Low voltage "	1.5 – 4

Factors affecting Dielectric strength:-

i) Dielectric strength decreases with rise of temperature in case of air. In case of liquid insulaters the effect varies with the type of oil & its viscosity

ii) Humidity generally decreases the value of dielectric strength.

Dielectric constant:-

- Capacitance is different for different insulating material, the property of insulating materials that causes the difference in the value of capacitance.
- Physical dimensions remaining same, is called dielectric constant or permitivity (ϵ)

Dielectric loss:-

There is a definite amount of dissipation of energy when an insulater is subjected to alternating voltage. This dissipation of energy is called dielectric loss.

So Dielectric power loss

$$P = VI\cos\theta$$

$$= V \times \frac{V}{X} \cos\theta \quad (\text{where } X \text{ is the capacitive reactance})$$

$$= V^2 \times 2\pi f C \sin\delta \quad (\cos\theta = \sin\delta)$$

Facters affecting Dielectric loss:-

The loss increases proportionately with the frequency of applied voltage.

) Presence of humidity increases the loss.

ii) Temperature rise normally increase the loss.

v) Voltage increase causes increased dielectric loss.

Mechanical properties:-

The properties affecting the selection of insulater are many but we shall consider only those which are of comparatively great importance.

Mechanical strength:-

Most solid insulaters have to withstand various loads during manufacture as well as during operation when used in an apparatus/equipment.

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 distance between two faces, ϵ is dielectric constant (or permitivity)

Also $\epsilon = \epsilon_0 \epsilon_r$

Where ϵ_r is the dielectric constant of the material & ϵ_0 is the dielectric constant or permitivity of vaccum ($\epsilon_0 = 8.854 \times 10^{-12}$ Farad per m).

Dielectric constants for different insulating materials

Material	Dielectric Constant (ϵ_r)
Paper	2.0 - 2.6
Mica	2.5 - 6.6
Glass	5.4 - 9.9
Marble	8.3
Diamond	16.5
Oil	2.2 - 4.7
Parafin	2.1 - 2.5
Procelain	5.7 - 6.8
Rubber	2.0 - 3.5
Wood	2.5 - 7.2
Water	70

e.g. strings of suspended procelain insulators have to bear a good amount of load, rotor windings of motors & generators have to bear centrifugal force of revolving rotors, plugs, sockets for domestic application have to withstand repeated operations.

The mechanical strength of insulating materials depends upon a number of factors given below:

i) **Temperature rise:-** Temperature rises as a result of heat generation in the conductor & the dielectric loss in the insulator.

High temperatures can adversely affect the mechanical strength of insulating materials

ii) **Climatic effects:-** Humidity can also adversely affect mechanical strength of insulating materials

Insulating materials are likely to be subjected to various types of mechanical stresses viz: tension, compression, resistance to abrasion, tear, shear & impact.

2) **Visosity:-**

Visosity in liquid dielectrics will affect manufacturing processes.

For example, in paper insulated cable the temperature at which the oil will penetrate through paper will depend on its viscosity

- The method to be used to purify the insulating oil used in transformers & other applications will depend upon the viscosity of the oil.

3. **Porosity:-**

- High porosity insulating materials will increase the moisture holding capacity & consequently adversely affect electrical properties. Therefore, normally it is not desired to have a dielectric of high porosity.
- However, in certian applications porosity is advantageous & is therefore desirable as for example when paper is to be impregnated with oil.

4. **Solubility:-**

- In certian applications insulation can be applied only after it is dissolved in some solvent. In such cases the insulating material should be soluble in certian appropriate solvents.

→ For example, varnish is dissolved in a solvent like Acetone to toluene & only then it can be applied. Such an insulation should not dissolve & be washed out in fluids it comes in contact with during operations.

- If the insulating material is soluble in water then moisture in the atmosphere will always be able to remove the applied insulation ...

ii) Thermal Properties :-

Various thermal properties are discussed below

Melting Points, Flash Points, volatility :-

Melting Point is desired that in the entire operating temperature range of cables the impregnating compound must not melt to avoid migration of oil.

Flash Point will impose restriction in manufacturing processes to avoid possible hazards of apparatus catching fire.

Volatility assumes importance from the fact that when a trapped gas is evolved from a volatile insulating material subjected to voltage stress, the breakdown is very rapid. So A volatile material cannot be a good insulator.

Thermal Conductivity :-

- An insulator with better thermal conductivity will not allow temperature rise because of effective heat transfer through it to the atmosphere. This property assumes great importance in high voltage apparatus where thickness of insulation is more.

Thermal expansion:-

- An insulator with a high coefficient of expansion poses problems. Repeated load cycles of an apparatus cause corresponding expansion & contraction of the insulator leading to the positivity of the formation of voids in it.
- These voids have been found to be the major cause of insulation breakdown. So thermal expansion is of significant importance where heavy currents are involved.

Heat resistance:-

- This is a general property which deserves that a dielectric should withstand temperature variation within desirable limits, without damaging its other important properties.
- If an insulator has favourable properties at ambient temperature but is not able to retain these properties to desirable extent at higher temperature. but is not able to retain these properties to desirable extent at higher temperature upto which it has to operate, it is not a good insulator.
- An insulator which is capable of withstanding higher temperatures without deteri...

Other properties can be used for operation for such higher temperatures which means that the current loading can be increased thus making the apparatus capable of handling more power.

Classification of Insulating materials on the basis of operating temperatures

- In view of the important part played by the thermal properties mentioned above it is obvious why the classification of dielectrics is made on the basis of operating temperatures

Effect of temperature increase on life of Insulator

- There is always some recommended operating temperature for an insulator. The operating temperature has a bearing on the life of the concerned apparatus.
- A thumb rule suggested by many experts is that life of insulation is halved for each 8 to 10°C rise above the recommended operating temperature for a given apparatus

Chemical properties:-

- Chemically a material is a better insulator if it resists chemical action.
- Certain plastics are found approaching this condition. Consequently their use is very much on the increase

- Plastics have replaced paper insulation in many applications because of the former being chemically inert & groscopic.

- However, chemical resistance requirements of insulations used in underground cables which are likely to operate under severe chemical condition due to water, salt, acids or alkalis will be more demanding than those of the insulations 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 insulators in two ways:

i) It acts on the surface of insulation
ii) It may be absorbed by the insulation

Moisture thus absorbed affects all the electrical properties adversely. However there are insulating materials like Paraffins, polythene, Polytetrafluroethylen (P.T.F.E) which are non-hygroscopic

Effect of contact with other materials:-

- Insulation remains invariably in contact with different types of materials like air, gases, moisture, conducting materials & structural materials.
- Unlike gases & moisture whose effect on insulation has already been considered, the conducting & structural materials have little effect due to contact with the insulation.
- There are some cases for example that of rubber in contact with copper, where chemical action takes place. To avoid this chemical action a coating of tin is applied to copper before putting on the rubber insulation.
- In capacitor using synthetic insulating oil, the oils react with the inner walls of the tank causing iron particles to mix with the oil which can adversely affect the insulating properties of the oil.

Ageing:-

- Ageing is the long time effect of:
  - i) Heat
  - ii) Chemical action
  - iii) voltage application

Classification of Insulating materials on the basis of Physical & Chemical structure :-

Insulating materials, on the basis of their physical & chemical structure may be classified in various categories as follows:

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 rubbers
x) Insulating resins & their products
xi) Laminates, Adhesives, Enamels & Varnishes

1) Fibrous materials:-

- Fibrous insulating materials are either derived from animal or from cellulose which is the major solid constituent of vegetable plants.
- Most of the fibrous insulating materials are from cellulose which consists of elognated particl called fibres in their structure
- Fibrous insulating materials

The important types of fibrous materials used are:- Wood, paper, card board, Insulating textiles. Asbestos.

Wood:-

- properly seasoned & impregnated wood is cheap & good insulating material
- wood is used for low voltage installations only & is light in weigt having density 0.5 to 1.0 gm/cm³
- Wood is very hydroscopic & after absorbing moisture tends to lose markedly its mechanical properties.

Electrical applications of wood:-

- Making terminal boxes, switch boards
- Used for round blocks, electric blocks, slot wedges in motor & generater windings.
- Instrument, equipment covers, handle for tools, Separaters in accumulaters.
- Used for sealing of H.T & L.T winding in transformers

Paper:-

- paper is made from cellulose or glass or asbestos which is employed for insulation purposes is a special variety known as tissue paper or Kraft paper.

Impregnated Paper Insulation:-

- The impregnated paper insulation is more reliable in electrical applications

Main features or advantages of impregnated paper insulation are as follows.

- Good mechanical strength
- Ability to withstand high temperatures
- Good chemical stability
- Comparatively less dielectric losses
- Non-inflammable
- Dielectric constant varying between 2.25 & 6.35
- Wide availability
- Ease of wrapping around the conductor
- Cheapness

Application of impregnated paper:-

Major application of impregnated paper are,

- Cable :- In all types of cables i.e. underground power cables, mining cables & submarine cables in complete operating voltage range of 220 kv to 400 kv

- Transformers:- paper insulation is frequently used in high voltage power transformers

- Capacitors :- paper dielectric duly impregnated has been used very successively in apparatus for generation, transmission & utilization of electric power

Cardboard:-

Cardboards are sheets of short fibres which are either resisters or stiff which are used for slot liners in electrical machines, coil frames & as insulation in oil immersed transformers

- Press board for card board is similar to paper except for its thickness whose insulation resistance is 10^7 ohm meter & dielectric strength is 50 kV/mm.

It is used for making slot wedges & liners for stator & rotor core stacks separators in transformer windings, slot lining.

Insulating textiles:-

- Both natural & synthetic fibers woven into cloth are called synthetic fibers example; cotton, silk, wood, jute, viscose, rayon, acetate, nylon, teflon, fibers, glass etc.
- They are cheaper & can be easily processed, highly mechanical strength & flexibility
- They are hygroscopic & of low dielectric strength, the electrical properties can be improved by impregnation.

Types of Insulating textiles:-

- Cotton
- Silk
- Vulcanised fiber (Paper treated with zinc chloride)

Application of cotton:-

- Cotton covered wires are used for transformers
- Rotor windings
- Stator windings

Silk :-

Properties of silk are Thin, strong, Non-hygroscopic, Better space factor than cotton, Low thermal conductivity.

Application of silk:-

- Cotton covered wires are used for transformers
- Rotor windings
- Stator windings

Vulcanised fiber:-

Properties of vulcanised fiber are tough, hence baked & treated with wax to improve electrical characteristics.

Application of vulcanised fiber:-

- Used as bushing
- Used as washer
- Used as low voltage insulation

Asbestos:-

- Asbestos is a mineral fibrous material which are longer the fiber, the higher is the grade of asbestos & greater is its cost. These fibers are strong & flexible.

2) Impregnated Fibrous Materials:-

(A) Impregnated paper dielectrics :-

Main features of impregnated paper insulation are

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

- Major applications of impregnated paper are in:

i) Cables:- In all types of cables i.e. underground power cables, mining cables & 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 varnishes & (ii) Oleobituminous varnishes

outstanding features of varnished textiles are

i) Good mechanical strength
ii) Good dielectric strength
iii) Low hygroscopicity
iv) low resistance to organic solvents

v) Limiting working temperature of 105°C

vi) oleobituminous varnished textiles are not resistent to oil.

· Applications of varnished or impregnated textiles:-

- This insulation is widely used for windings in electric machines of low & medium ratings.
- It is also used in cables as wrappers & liners
- In the form of adhesive tape the materials used by electricians as on the spot insulation for jobs relating to electric installation.

3) Nonresinous Materials:-

Non resinous materials are classified as follows

(A) Bitumens:-

Special features of bitumens are:

i) Highly soluble in mineral & synthetic oils

ii) Easily oxidized

iii) Resistant to moisture penetration

iv) Poor insulating property

v) softening point varies between 30°c to 140°C depending on the variety

vi) Acid & alkali resistant

vii) specific gravity is about one

Application of bitumens:- Bitumen is normally used in electric engineering because of its outstanding property of being water resistant.

Bitumens find wide applications in underground cable for the protection of lead & steel armour against corrosion.

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

(B) Waxes :-

(a) Paraffin & Microcrystalline waxes :-

Special features of these waxes are :-

i) easily soluble in mineral & synthetic insulating oils

ii) Marked change in volume when waxes changes state i.e. from liquid to solid or vice versa

iii) Mechanically weak.

iv) Poor electrical properties which become proper when heated.

v) Paraffin waxes get oxidized when they are heated beyond melting point.

Application of paraffin & microcrystalline waxes:-

- The excellent sealing property of waxes makes them fit for use as sealing material.
- Microcrystalline waxes having high melting points are used as a constituent material to make non-draining impregnated compound which is extensively used for mass impregnated non draining (MIND) paper cables, 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.
- It also suffers from shrinkage or expansion when undergoing change of state.
- Their dielectric properties are satisfactory. Dielectric constant ranges between 2 & 3

Application of natural waxes:-

- These waxes are mixed with insulating oils to improve the viscosity & pour point of the latter, to form non draining cable compound
- These waxes also used as a constituent of sealing compound.

4) Insulating Liquids:-

The various important insulating liquids are described below:

a) Mineral insulating Oils:-

- These oils are derived from crude petroleum. Distillation of crude petroleum gives many industrial byproducts like alcohols, kerosene, lubricating oils, asphalts, waxes & insulating oils.
- Insulating oils obtained thus are not suitable for present day requirements unless they are properly

modified for high oxidation resistance, good thermal stability & other specific engineering requirements.

- These oils find frequent use in transformers, cables & capacitors.

b) Synthetic liquids :-

- Synthetic liquids are sold by different manufacturers under different trade names like Askarels, Aroclors, Pyranols etc.

- The synthetic oils are very resistant to oxidation & to fire hazards, the use of these liquids in transformers is increasing because of these reasons.

c) Miscellaneous Insulating liquids :-

i) **Vegetable oils:-** These oils are obtained from seeds of pulp. Linseed, cotton seed, sunflower, soyabean, caster, palm, olive peanut oil etc. were the liquids used in past.

- The main reason of their being used was their easy availability but these liquids are rarely used in the present day.

ii) Flourinated liquids:- These liquids are similar to synthetic liquid which shows a greater volatility at a prescribed temperature but chemical instability is less than that of

- High temperature operation & excellent cooling properties are assets of these liquids. Flourinated liquids are sometimes used in transformer

iii) <u>Silicon liquids</u> :- These liquids are found to possess some exceptional properties which are stability at high temperatures & very wide range of viscosity from as low as one to as high as 1000000 centistocks.

- The dielectric constant of these liquids is same as that of mineral oils (2.7 to 2.8), power factor is very low.
- These liquids are sometimes used in transformers

5) Ceramics :-

The features of ceramics are

i) Ceramics are hard, strong & dense

ii) Not affected by chemical action except by strong acids & alkalies

iii) Stronger in compression than in tension

iv) Stability at high temperatures likely to occur in electrical engineering applications

v) Excellent dielectric properties

vi) Weak in impact strength & can not be used as self supporting thin films like paper, cotten etc

Applications of ceramics :-

Major applications are as follows :

a) Porcelain Insulaters :- Porcelain materials are used to make many different types of insulaters, like transformer bushing pins, suspension insulators for transmission & distribution lines, disconnecting switches, porcelain parts used for switches, plugs & sockets, fuse holders, telephone insulators etc.

b) Line Insulaters :- Porcelain finds one of the largest applications as line insulaters. Proper design of an insulater helps in overcoming the problem of reduced surface resistivity & flash over due to rain & accumulation of dirt.

c) Other ceramic material :-

- Relatively high loss facter & its further increase at higher temperatures & frequencies has restricted the use of procelative which has given rise to other ceramic insulaters.

i) Steatite :- A proper mixture of clay & talc (hydrated magnesium silicates) dried & then fired with the addition of certian other materials like felspar, magnesite etc makes steatite.

- Steatite is used in making equipment for high frequency systems. Also when thermal shock resistance is desired, steatite is used.

ii) <u>Alumina</u> :- Alumina is characterized by high structure limiting temperature (upto 1800°c) less water absorption, high compressive strength.

- Alumina excels in heat conduction having 20 times more conductivity than procelain.

iii) <u>Titanate ceramics</u>:- Inclusion of certian titanates like barium titanate, lead titanate etc. during manufacture makes titanate ceramics.

- Titanate ceramics have an astoundingly high dielectric constant. Barium titanate ceramic can possess a dielectric constant of upto 10000. so exceptionally high value offeres big advantage in capaciter design.

iv) <u>oxide free ceramics</u>:- These ceramics excel in their extreme heat resistance property, the melting point of nitride exceeds 2000°c & this can be used at a temperature as high as 1700°c in oxygen free medium.

- Boron nitride is used in manufacturing synthetic mica & metal crystals for making transisters.

6) Mica & mica products:-

Mica is an inorganic material & is one of the best natural insulating materials available from electrical utility point of view of the following two varieties viz Muscovite mica & phlogopite mica.

a) Muscovite Mica:- The basic chemical composition of Muscovite mica is $KH_2Al_3(SiO_4)_3$

Some properties of muscovite mica are

i) Strong, tough & less flexible
ii) colourless, yellow, silver or green in colour
iii) Insulating properties are very good
iv) Abrasion resistance is high
v) Oils & hydrofluoric acid act on it adversely.

Application of muscovite mica :- It is generally used where electrical requirements are severe. High dielectric strength allows it to be used in capacitor & high abrasion resistance enables its use in commutators.

b) Phlogopite Mica :- The basic chemical composition is $KH(MgF)_8 Mg Al(SiO_4)_3$ is also called Magnesium Mica.

Some properties of Phlogopite mica 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 so to acids

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

v) Greater thermal stability than that of muscovite mica.

<u>Applications of Phlogopite mica</u>:- It is used when there is greater need of thermal stability as in domestic appliances like irons, hot plates, toasters etc.

c) <u>Mica products</u>:- Some important mica products are
i) Glass bonded Mica
ii) Synthetic Mica
iii) Mica paper
iv) Manufactured mica.

i) <u>Glass bonded Mica</u>:- Ground mica flakes & powdered glass when moulded makes glass bonded mica & the ratio of mica & glass is between 40/60 to 60/40 range..

- It is impervious to water & chemically stable which has low dielectric loss & high dielectric strength.
- It is machinable & can be moulded very accurately. This material finds its use in high humidity & high ambient temperature atmospheres.

Synthetic Mica:- It is the best grade muscovite mica although synthetic mica possesses the many technical defects of natural mica, yet the principal reasons for its manufacture lies in the fact that dependence on the limited resources of the best grade muscovite natural mica is completely eliminated.

) **Mica paper**:- Mica is broken into small particles in aquous solution out of this, sheets of mica paper are produced by a process similar to that adopted for the manufacture of cellulose paper. Mica paper products are suitable for use as insulation for armature & field coils of rotating machines.

) **Manufactured Mica**:- When mica flakes are held together with adhesives the product is called manufactured mica or mica plate. Manufactured mica is made use of in commutat[ors], electrical heating devices, motor slot insulation, transformers etc.

) **Asbestos & Asbestos products**:- Asbestos is the term used to designate a class of naturally occuring long fibre minerals.

It find extensive use in electrical equipment as insulation because of its ability to withstand very high temperature.

- Two types of asbestos are naturally available

  1. Chrysotile Asbestos
  2. Amphibole Asbestos.

Applications of Asbestos:-

- It is used in low voltage work as insulation in the form of rope, tape cloth & board
- It is used as insulation in wires & cables under high temperature conditions, in coil windings & in end-turn insulation in motors & generators as conductor insulation & layer insulation in transformers, as arcing barrier in switches & circuit breakers.

Industrial Asbestos products:- Some of the asbestos products in use are as follows.

i) Asbestos roving :- Chrysotile asbestos fibres reinforced with cotton or synthetic organic fibres make asbestos roving.

- It finds use in insulation of cables & conductors & in heating devices.

ii) Asbestos paper & board :- In actual use asbestos paper is further reinforced with cotton or synthetic fibres or glass.

- Asbestos paper is applied as wrapper, barrier insulation in transformers, insulation for wires & cables.

compressive strength & also excels in heat conduction having 20 times more conductivity than procelain.

iii) <u>Titanate ceramics</u> :- Inclusion of certian titanates like barium titanate, lead titanate etc during manufacture makes titanate ceramics

iv) <u>Oxide free ceramics</u> :- Some ceramics are there which has no oxides means instead of oxides. they consist of nitrides, sulphides, carbides etc. Boron nitride is used in manufacturing synthetic mica & metal crystals for making transisters

<u>Piezo electric ceramic transducer elements</u> :-

Piezo electric ceramic transducers are based on lead zirconate lead titanate compositions which have good efficiency for electrical to mechanical energy conversion & vice versa.

There are three types of ceramic material

<u>Type-1</u>
Low power ceramic materials :- Its application in low power transducers, accoustic sensing elements, flaw detection probes & gramo phone pickups.

<u>Type-2</u>
High power ceramic materials :- Its application in high power electro accoustic devices, ultrasound cleaners, high voltage generaters.

<u>Type-3</u>
The third grade is stabilised grade :- These are used on Lead zirconate titanate

occur in electrical engineering applications
e) Excellent dielectric properties
f) Weak in impact strength

Applications of Ceramics:-

Major applications are as follows

a) procelain insulators:- procelain materials are used to make many different types of insulators like transformer bushing pins, suspension insulators for transmission & distribution lines, disconnecting switches, procelain parts used for switches, plugs & sockets, fuse holders, telephone insulators etc.

b) Line Insulaters:- procelain find one of the largest applications as line insulaters

c) Other ceramic material:- Apart from procelain there are other ceramics which are Stealite, Alumina, Titanate ceramics, oxide free ceramics

i) Stealite:- A proper mixture of clay & talc (hydrated magnesium silicate) dried & then fired with the addition of certian other materials like felspar, magnesite etc. makes steatite

- It is used in making equipment for high frequency systems & when thermal shock resistance is desired steatite is used.

ii) Alumina:- This is primarily made of Aluminium oxide & is characterized by high structure limiting temperature (up to 1800°C) less water absorption high

iii) Asbestos tapes:- Tapes are made by weaving asbestos yarn & then either varnished or resin impregnated.

Asbestos tapes are used for equipment required to work at temperatures higher than those recommended for class A insulation.

iv) Woven asbestos types:- Asbestos cloth is woven from asbestos yarn which is used in moulded & laminated structures for electrical or mechanical purpose.

v) Asbestos cement:- About 20 percent asbestos fibres & 80 percent portland cement are the main constituents of asbestos cement.

These cements find their use in switch panel construction & in arcing devices.

8) Glass:- Glass is an inorganic material made by the fusion of different metallic oxides which is normally trasparent, brittle & hard.

Applications of glass:- 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 etc also make use of glass in abundance although not as conventional insulater.

The various commercial varieties of glass used in the field of electrical engg. are given below.

a) **Fused Quartz or silica glass**:- Silica when heated to the temperature of fusion & then cooled is known as silica glass.

b) **Borosilicate glass (Pyrex)**:- This glass requires about 28 percent oxide of boron along with other oxides. These glasses posses good electrical properties but not as good as that of Quartz.

c) **Fibre glass insulation**:- Fibre glass insulation is capable of withstanding the temperature of 130C

- It posses good electrical & mechanical properties & sufficient flexibility to be moulded into required shapes.

d) **Epoxy glass**:- The epoxy glass is made by joining glass fibre layers with a thermosetting compound.

- Its main feature of non absorbant of water & immunity with alkalies & acids makes it suitable to be used in PCB making terminal holders & instrument case etc.

Insulating gases:-

Introduction:- The various insulating gases are -

Simple gases	Hydrocarbon gases	Oxide gases	Electronegative gases
Air, Nitrogen, Hydrogen, Helium etc.	Carbon dioxide, Sulphur dioxide	Methane, Ethane, propane etc.	Freon & sulphur hexafluoride

Air & nitrogen, are commonly in use as insulator.

Commonly used insulating gases:- Commonly used insulating gases are discussed as follows.

1) **Air:-** Air acts as an insulation in many electrical applications in addition to the solid or liquid insulating material provided

Common examples are overhead transmission lines, condensers, plugs, switches, various electrical machines & apparatus etc.

2) **Nitrogen & Hydrogen:-** Like air nitrogen is also commonly used as insulater in electrical equipment.

In many high voltage applications air is replaced by nitrogen to prevent oxidation of the other insulating materials.

Nitrogen under pressure is used as the only insulater in certian types of capacitors.

- pressurized nitrogen gas in conduction with oil treated paper insulation is used in high voltage gas pressure cables.

Hydrogen is rarely used as an insulator & also commonly used for cooling purposes in electrical machines

- Hydrogen is also used in electrical rotating machines to reduce windage loss.
- The hydrogen gas acts as one of the materials layers through which heat must pass from the point of its origin in the functioning of the machine to the outside wall or other points of dissipation.
  e.g. Gas filled capacitors & sealed gas insulated transformers.

3) Sulphur-hexafluoride:- When sulphur is burnt in an atmosphere of fluorine, sulphur hexafluoride is formed.

- It has high dielectric strength & is non inflammable
- It is characterized by cooling property which is superior to those of air & nitrogen.
- It has found applications in transformers & electric switches
- The presence of sulphur in the molecules under some conditions, involve corrosion of the contacting surfaces

Chapter - IV

Dielectric Material

Introduction:-

- The material which are capable of retarding the flow of electricity or heat through them are known as dielectric or insulators.
- The properties which are taken into consideration for an insulator are the operating temperature & breakdown voltage.
- However when it is used to store electrical charge it is known as Dielectric material.

The electrical conductivity of dielectric material is quite low & the band gap energy is more than 3eV.

- This is the reason why the current cannot flow through them.

Dielectric Constant:- The proportionality constant in the relation between the electric flux density(D) & the electric field intensity(E) is known as Permittivity(ϵ) or dielectric constant.

- If the medium to which the electric field is applied is a free space(or vacuum), the proportionality constant or vacuum is ϵ_0 of value 8.854×10^{-12} farad meter^{-1}.

- The dielectric constant of a material may be expressed as ϵ_r relative to that of a vacuum by $\epsilon_r = \frac{\epsilon}{\epsilon_0}$.
- So, the relation of electric flux density & electric field intensity is given by $D = \epsilon_0 \epsilon_r E$

where ϵ_r is a dimension less quantity & is known as relative dielectric constant, which is determined by the atomic structure of the material.

<u>Polarization</u>:- The dipole moment per unit volume is called the <u>polarization P</u>.

$P = \frac{p}{\text{volume}}$ where p is the dipole moment & P is the polarization in coulomb·meter^{-3}.

Considering a parallel plate capacitor having two metal plates of area A & separated in vacuum by distance d & having a battery of voltage V connected across it.

- The electric field E between the plates is given by V/d volt m^{-1} arising from the charge density ±Q on the plates.
- The relation between Q & E is given by $Q = \epsilon_0 E$. Q can be considered as a source of electric flux lines in the space between the plates

compensate for these, which has become bound.

- There is now more charge density Q on the plates some of which is tied up & is not contributing to the field E in the dielectric.
- The amount of charge that is contributing to the field is the same as before & $Q' = Q + Q_s$ where Q_s is the bound charge density, Q has been multiplied by a factor ϵ, such that

$$Q' = \epsilon_r Q,$$

- Electric field density is now given by

$$D = \epsilon_0 \epsilon_r E$$

$$\text{or } D = \epsilon_0 E + Q_B$$

The bound charge density is called polarization P which is identical with the dipole moment per unit volume.

- The polarization may be expressed in terms of elementary dipole moments p by

$$P = N \cdot p$$

where N is the number of dipoles per unit volume.

- The density of this flux lines is the electric displacement D.

$$D = Q = \epsilon_0 E$$

Now consider that the battery is still connected & a dielectric medium is introduced to fill the space between the plates.

- The medium becomes polarized by the field E & dipoles appear throughout the material, lined up in the direction of the field.
- All dipole ends of opposite charge inside the material will cancel, but there will be an uncompensated surface charge on the plates, positive on one plate & the negative on the other plate.
- These surface charges ~~on the plates~~, ~~positive on one plate & the~~ will attract & hold corresponding charges of opposite sign on the plates because the latter, unlike dipoles are able to move freely.
- The field in the dielectric will be still E. If the effects of some of the original surface charges have been neutralized by being bound to surface dipole ends, E can only be maintained by the flow of more charges on the battery to

Dielectric loss:- The dielectric material separating the two electrodes or conductors is stressed when subject to a potential.

- When the potential is reversed, the stress also reversed this change of stress involves molecularly arrangement within the dielectric.
- This involves the energy loss with each reversal because the molecules have to overcome a certian amount of internal friction in the process of alignment.
- The energy expanded in the process is released as heat in the dielectric.

The loss appearing in the form of heat due to reversal of electric stresses, compelling molecular arrangement is known as dielectric loss.

Electrical conductivity of Dielectric & their breakdown

The dielectric material is used in electrical & electronic circuits as insulators & as a medium in capacitors.

- When the applied electric field is increased, the potential difference across it also increases
- A limit is reached when the dielectric ceases to work as an insulator & a spark occurs

This limiting value of the voltage is known as breakdown voltage, which measures the strength of dielectric.

Therefore, dielectric strength = $\dfrac{\text{Breakdown voltage}}{\text{Thickness of the dielectric}}$

<u>Conduction of Gaseous dielectric</u>:- Air is the common gaseous dielectric. Cosmic rays & ultraviolet rays cause the natural ionization in air.

- Since the opposite charges are equal, natural recombination takes place continuously to check further ionization of whole air.
- The free charges do not go for recombination if the medium is within an electric field.
- Due to the application of the electric field, free charges move to their respective potential plates, causing a flow of current known as leakage current.
- The magnitude of current is dependent upon the applied voltage, with the increase in voltage the directed flow of electrons & ions increases as compared to random motion in low voltage.
- If the applied voltage is further increased, the energy of free charges becomes sufficient to force out electrons even from natural atom.
- Each free electron moves at a great velocity, collides with other ~~[struck-out]~~ neutral atoms & knocks out free electron out of them.

- This process increases in geometric progression & the leakage current increases sharply in result to cause the breakdown of dielectric & the corresponding voltage is known as breakdown voltage.

<u>Conduction of liquid dielectric</u> :- The liquid dielectric along with impurities of solid particle has more ability to conduct.

- The impurities get electrically charged & act as a current carrier & the fibrous impurities make the alignment of ions in a straight path for which the conductivity in liquid gets faster.
- In an uncontaminated liquid dielectric, such ion bridge cannot be formed.
- The breakdown of an uncontaminated liquid dielectric takes place due to the ionization of gases present in the liquid.
- The applied voltage ionizes the gas in liquid & the electric field intensity increases which causes further ionization & ultimately the breakdown of dielectric takes place.

Conduction of solid dielectric:- Electrical conductivity of solid dielectrics may be electronic, ionic or both.

- In electronics current flow, the flow of current is due to the movement of electrons towards the positive electrodes, while ionic current flow is due to the movement of positively charged ions towards the negative electrode.
- The impurities also play the role of conductivity in the dielectric. At low temperature the conductivity of solid dielectric is due to impurities only.
- At higher temperature the leakage current depends upon the contribution of free ions of the base dielectric.

Breakdown of solid dielectrics may be electro thermal or electrical & heat produced due to dielectric loss causes electro thermal breakdown & in effect destruction of dielectric takes place.

- If the dielectric is not able to radiate away the generated heat caused by dielectric loss & the applied voltage is retained for a long period the material gets melted.

- The electrodes get short circuited & solid dielectric is not recoverable after its breakdown like liquid or gaseous dielectric.

Properties of Dielectric Materials:-

Some of the main properties of important dielectrics used in practice are given in following table.

Material	Dielectric Constant	Dielectric Strength	$\tan\delta$	Max working temp. °C	Thermal Conductivity (mW/mK)	Relative density
Air	1	3	–	–	0.025	0.0013
Alcohol	2.6	–	–	–	180	0.79
Asbestos	2	2	–	400	80	3.0
Cellulose film	5.8	28	–	–	–	0.08
Cotton fabric (dry)	–	0.5	–	95	80	–
Impregnated	–	2.0	–	95	250	–
Ebonite	2.8	50	0.005	80	150	14
Glass (flint)	6.6	6	–	–	1100	4.5
Glass (crown)	4.8	6	0.02	–	600	2.2
Mica	6	40	0.02	750	600	2.8
Dry paper	2.2	5	0.007	19	130	0.82
Impregnated paper	3.2	15	0.06	90	140	1.1

Material	Dielectric Constant	Dielectric Strength (KV/mm)	tanδ	Max working temp. at °C	Thermal Conductivity (mW/mK)	Relat. density
Quartz	5.7	15	0.008	1000	1000	2.4
Vulcanized Rubber	4	10	0.01	70	250	1.5
Resin	3	—	—	—	—	1.1
Fused silica	3.6	14	—	—	—	—
Silk	—	—	—	95	60	1.2
Sulphur	4	—	0.0003	100	220	2.0
Water	7.0	—	—	—	570	1.0
Paraffin wax	2.2	12	0.0003	35	270	0.88

Application of Dielectrics -

The most common application of dielectric is as a capacitor to store energy. Capacitors are classified according to use of dielectrics used in their manufacture.

i) Capacitors using vacuum, air or gases as dielectric
ii) Capacitors using mineral oil as dielectric
iii) Capacitors using a combination of solid & liquid dielectrics
iv) Capacitors only with solid dielectric like glass & mica etc.

Chapter-V
Magnetic Materials

Introduction:-

- Materials which can be magnetized are called magnetic materials. When magnetized, such materials create a magnetic field around them.

The property of a material by virtue of which it allows itself to be magnetized is called Permeability. For most materials, except those which are called magnetic materials, the value of permeability is constant & is the same as for free space. The permeability of free space is denoted by μ_0 & equals $4\pi \times 10^{-7}$ & the permeability of air is almost same as for free space i.e. $4\pi \times 10^{-7}$

For magnetic materials, permeability, μ is given by : $\mu = \mu_0 \times \mu_r$ ——— (1)

Where, μ_r is called relative permeability & the value of μ_r varies from material to material & depends on the degree to which the material is capable of being magnetized. It may have a value as high as 2500.

- In free space the magnetic flux density B is related to the intensity of magnetization H. as follows : $B = \mu_0 \times H$ ——— (2)

Where B is measured in wb/m^2 & H in Ampere-turns/m & $\mu_0 = 4\pi \times 10^{-7}$

- In a solid the value of permeability is different from μ_0 & may be expressed as μ.

Thus in a solid material: $B = \mu H$ ——— (3)

where $\mu \neq \mu_0$

The expression (3) may be written as

$$B = \mu_0 (H + M) = \mu H \quad \text{——— (4)}$$

M in expression (4) is called the magnetization of t[he] solid. Thus the solid material is somehow responsible for the appearance of the extra magnetic flux density $\mu_0 M$ in addition to the flux density in free space $\mu_0 H$ (For a non-magn[etic] material expression (4) becomes $B = \mu_0 H$.

The magnetization, M of a material ma[y] be regarded as resulting from the alignment of magnetic dipoles of the material parallel to the applied field intensity H.

- This means that the more the applied field intensity the greater will be the number of dipoles which will align parallel to the applie[d] field.
- Therefore, the magnetization is proportional to the applied field.

Thus $M \propto H$

$$\Rightarrow M = \chi \times H \quad \text{——— (5)}$$

Where χ is the constant of proportionality & is called susceptibility.

Classification of Magnetic materials:-

Magnetic materials classified as :

a) Diamagnetic material

b) Paramagnetic "

c) Ferromagnetic "

1) **Diamagnetic material** :- The materials which are repelled by a magnet are known as diamagnetic materials.

e.g. Zinc, Mercury, lead, sulphur, copper, silver.

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

This means that the relative permeability μ_r of a diamagnetic material is negative which makes diamagnetism unimportant for electrical engineering applications.

2) **Paramagnetic materials** :- The materials which are not strongly attracted by a magnet are known as paramagnetic materials.

e.g. Aluminium, Tin, Platinum, Manganese etc.

On application of an external magnetic field the permanent magnetic dipoles orient themselves parallel to the applied magnetic field & give rise to a positive magnetisation M

Substituting expression (5) in (4) we have :

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

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

$$\Rightarrow B = \mu_0 \mu_r H$$

where $\mu_r = (1 + \chi)$ is called the relative permeabi[lity] of the medium. For a non magnetic material $\chi = 0$ i.e. $\mu_r = 1$

Relative permeability depends upon the nature of the material & on temperature.

- When relative permeability is positive the magnetic dipoles arrange themselves in the sam[e] direction as the applied field intensity.

- When the relative permeability is negative the magnetic dipoles align themselves in opposite direction to the applied field; in that case M in expression (4) assumes a negative value which means that the flux density decreases when it is applied in such a material as compared to that in free space.

The relative permeabilities of paramagnetic materials are therefore very approximately unity. Thus paramagnetic materials have negligible application in the field of electrical engineering.

c) <u>Ferromagnetic materials</u> :-

The materials which are strongly attracted by a magnet are known as ferro-magnetic materials. e.g. Iron, Nikel, Cobalt etc.

When a weak external magnetic field is applied, it is not enough to cause any change in the orientation of the domains & the flux density with such low applied field is entirely due to the externally applied magnetic field.

When the externally applied magnetic field is increased, a stage is reached when although it is still weak, the domains will start orienting themselves such that their resultant magnetic field coincides with the externally applied magnetic field & the material will develop strong magnetic field of its own

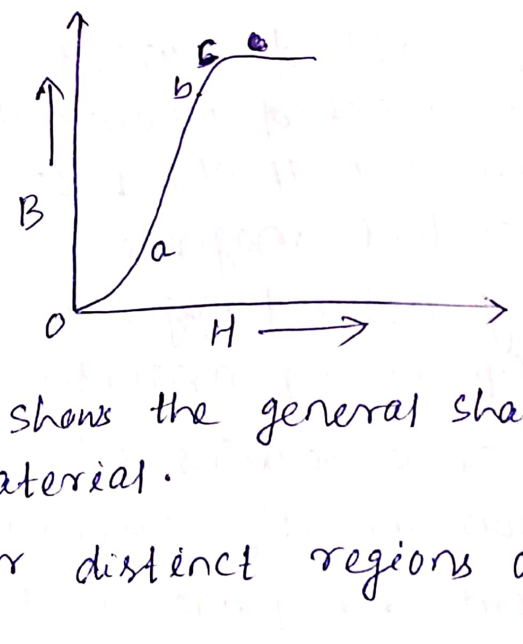
However, there are some domains whose original magnetic orientation greatly diverges from that of the applied field & require a stronger external field to be able to orient their magnetisation in the same direction as the applied field.

This means that those domains whose original direction of magnetisation is less divergent from that of the applied field, will be aligned by a comparatively weak external field & the external field will have to be made stronger & stronger in order to align the domains whose direction of magnetization is more & more divergent from that of the applied field.

- As a result the rate of strengthening of the internal magnetic field decreases with increase in the applied magnetic field & ultimately gives rise to a state of magnetic saturation.

Magnetisation curve:-

- The curve drawn giving relationship between flux density 'B' & magnetizing force 'H' is known as magnetization curve or B-H curve.



- This figure shows the general shape of B-H curve of magnetic material.
- It has four distinct regions oa, ab, bc & the regions beyond c.
- During the region oa the increase in flux density is very small, in region ab the flux density B increases almost linearly with the magnetizing force H, in region bc the increase in flux density is again small & in region beyond point c,

Where K = is a constant is known as Steinmetz hysteresis coefficient

f = Frequency of reversal of magnetization

B_m = Maximum flux density

V = volume of magnetic material

Eddy current :-

- When magnetic material is placed in alternating magnetic field, it cuts the magnetic flux.
- According to laws of electromagnetic induction an emf is induced.

This emf causing current is known as eddy current.

The power loss due to the flow of this current is known as eddy current loss.

- The expression for eddy current loss can be represented as

Eddy current loss = $K B_m^2 f^2 t^2 V$ watts.

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

B_m = Maximum flux density

f = Frequency of magnetic reversal

t = Thickness of lamination

V = volume of magnetic material

the flux density B is almost constant.

- The flat part of the magnetization curve corresponds to magnetic saturation of the material.

Hysteresis :-

- Hysteresis is especially pronounced in materials of high residual magnetism such as hard steel.
- In most cases hysteresis is a liability as it causes dissipation of heat, waste of energy & humming due to change in polarity & rotation of element magnets in the material.

If a magnetic substance is magnetized in a strong magnetic field it retains some portion of magnetism after the magnetic force is withdrawn.

- The phenomenon of lagging of magnetization or induction flux density behind the magnetizing force is known as magnetic hysteresis.
- The losses due to hysteresis is known as hysteresis loss which depends upon the maximum flux density B_m & frequency of variation of flux is expressed as:

Hysteresis loss $= K B_m^{1.6} f V$ J/s or Watt [Joule per sec]

Curie point :-

A critical temperature above which the ferro-magnetic material lose their magnetic properties is known as Curie point.

Magnetostriction :-

When ferromagnetic materials are magnetized a small change of dimensions 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 fields there is a rapid & continuous extension & contraction of the material

- This is called magnetostriction which is the major cause of hum in transformers & chokes.

Soft & Hard magnetic materials :-

All ferro-magnetic material may be divided into two types.

a. Soft magnetic materials
b. Hard magnetic materials

Materials which have a steeply rising magnetization curve, relatively small & narrow hysteresis loop & consequently small energy losses during cyclic magnetization are called as <u>soft magnetic materials</u>.

- Soft magnetic materials are soft iron, nickel iron alloys & soft ferrites

Magnetic materials which have a gradually rising magnetization curve, large hysteresis loss & consequently large energy loss of each cycle of magnetization are called <u>hard magnetic material</u>

- Hard magnetic materials are carbon steel, tunsten steel, cobalt steel, alnico, hard ferrite

<u>Soft magnetic materials:-</u>

- Soft magnetic materials are used for the construction of cores of electric machines, transformers, electromagnets, reacters, relays.
- In order to keep the magnetizing current & iron losses low using a low flux density, it increases the cross sectional area of magnetic path.

Hard magnetic materials:-

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

The hard magnetic materials are carbon steel, tungsten steel, cobalt steel, alnico, hard ferrites.

Carbon steel, Tungsten steel, cobalt steel:-

- As the soft magnetic material have narrow hysteresis loops, so when carbon is added in a material its hysteresis loop area is increased.
- Although it is cheap, magnets are made from carbon steel less their magnetic properties very fast under influence of knocks & vibrations.
- When materials like tunsten, chromium or cobalt are added to carbon steel, its magnetic properties are improved.

Alnico:-

- It is known as Aluminium-nickel-Iron-cobalt.
- Alnico are commercially the most important of the hard magnetic materials.
- Large magnets are made by special casting technique & small one by powder metallugy.
- As cobalt steel is cheaper so for this reason permanent magnets are most commonly made of Alnico

Hard ferrites:-

- Hard magnetic ferrites like $BaO(Fe_2O_3)_6$ are used for the manufacture of light weight permanent magnets due to their low specific weight.

The magnetic material for the core of electrical machines & transformers should have high saturation value & high permeability to keep the magnetizing current within reasonable low values.

When the core is to be used for alternating magnetic fields the core should be a such material as to produce small iron losses.

Pure iron :-

Pure iron is a ferrous material with an extra low carbon content. e.g. Low carbon steel, electrolytic iron.

The resistivity of pure iron is very low by virtue of which it gives rise to large eddy current losses when operated at high flux densities in alternating magnetic fields.

Pure iron is used in many kinds of electrical apparatus & instruments as magnetic material core for electromagnets, components for relay electrical instruments.

Iron silicon alloys:-

The chief alloying constituent is silicon which is added to iron in amounts from about 0.5 to 5% by weight.

- Iron silicon alloy usually known as silicon ste which is generally used in transformers, electrical rotating machines, reactors, electro-magnets & relays.

Silicon sharply increases the electrica resistivity of iron thus decreasing the iron loss due to eddy currents which increases the permeability at low & moderate flux densiti but decreases it at high densities.

- Addition of silicon to iron reduce the hysteresis loss & the magnetostriction effect is reduced.

- Addition of silicon is valuable because it facilitates the steel making process.
- Alloying of low carbon steel with silicon increases the tensile strength & reduces ductivity making steel brittle & also makes silicon alloyed steel difficult to punch & shear.

Grain oriented sheet steel :-

- As the ferro magnetic material have a crystal structure so every crystal of ferro magne substance has a particular direction along which it offers high permeability. so it most easily magnetized.

Such axes along which the crystals have high permeability and are more easily magnetized are called as easy or soft direction.

- Along any axis other than the easy direction, the crystal has low permeability & is therefore more difficult to magnetize. Such axes along which the crystal has low permeability are called as hard direction.

For easy magnetization the crystal directions of electrical sheet should be so oriented that their axes are paralleled to the direction in which the external magnetic field is applied. This is achieved in practice by carefully controlling the rolling & annealing of silicon iron sheets.

- The direction of easy magnetization then lie in the direction in which the steel is rolled in the mill.

Sheet steel which has been rolled such as to give easy direction to all its crystals is called "textured" or grain oriented steel.

Magnetic Anisotropy :-

- The directional dependence of magnetic property under heading grain oriented sheet steel is known as magnetic anisotropy.

- It is clear that in bulk magnet a great improvement will result if the individual preferred axes are aligned parallel & along the axis of magnetization.
- A substantial improvement in residual magnetization & coercive force will result from parallel organization of the domain movements.

The application of this technology is prevalent in the manufacture of permanent magnet.

Annealing:-

- The magnetic properties of ferromagnetic material are affected by strain due to mechanical working like punching, milling, grinding, machining.
- The magnetic properties including the correct crystal direction by heat treatment. Since mechanical stressing disturbs the crystal orientation, it is essential to perform that treatment once again after all mechanical operation have been completed.

Soft ferrites:-

- Ceramic magnet called as ferro magnetic ceramic & ferrites which are made of an iron oxides, Fe_2O_3 with one or more divalent oxides such as NiO, MnO or ZnO.
- These magnets have a square hysteresis loop & high resistance to demagnetization.
- The great advantages of ferrites is their high resistivity.
- The ferrites are carefully made by mixing powdered oxides compacting & sintering at high temperature.
- High frequency transformers in television & frequency modulated receivers are almost always made with ferrite core.

CHAPTER - VI

MATERIALS FOR SPECIAL PURPOSES

Special Purpose materials:-

Materials used in the field of electrical engineering for special purpose like in fuses, solders, bimetal etc.

- The special purpose materials are classified into the following six categories.
    - protective materials (lead, Plants, steel tape etc)
    - Structural materials (cast iron, concrete, cement etc)
    - Thermocouple materials (copper/constantan etc)
    - soldering, welding, brazing materials
    - Fuse materials (tin, lead etc)
    - Galvanizing tining electroplating materials (nickel, copper etc)

Protective materials:-

- The protective materials are more essential for every structural materials in electrical engineering.
- The protective material will provide protection against atmospheric effects like corrosion.
- The most commonly used materials for this purpose are lead, paints, steel tapes, wires & strips, varnishes Bitumen's etc.

Lead

- Lead is obtained from lead sulphide(PbS) which is the chief lead ore.
- Lead sulphide is also called galena or galenite which contains about 86% lead.
- The ore is first roasted to remove sulphur

$$2PbS + 3O_2 \rightarrow 2PbO + 2SO_2$$

- Lead oxide is then mixed with some quantity of tome & heated in a furnace resulting in metalic lead.

Application:-

- It is used in storage batteries for its electrodes
- It is used as sheathing in cables.
- It is used as a fuse materials(ie. fuse link wires because of low melting point.
- It is used as solders when alloyed with tin
- For making cable joints, Lead wires are commonly

Paint:-

- A paint is a dispersion of pigments in a drying o with the addition of 2 thinners
- Plasticizers are also added in paints to reduce the defect of craking in films & to get smooth film from paint.
- There are large variety of paints used to protect the structural materials(like steel, wood)

from atmospheric effects.

- these includes paints, enamel paints, emulsion paints, plastic paints, cement paints, aluminium paints, cellulose paints, coal tar paints, bituminous paints, varnish paints. etc.

Steel tapes, wires & strips:-

Steel tapes, wires & strips are commonly used as protective materials in

- Mining cables
- Underground cables
- For binding of cables
- For sporting services cables to avoid say.

Thermocouple materials:-

- Thermocouples are the most commonly used thermometers used for measurement to temperature which consists of two different conducting wires jointed at two junctions.
- one junction is maintained at a reference temperature, usually melting point of ice which is called cold junction.
- The other junction is maintained to the unknown temperature which is called the hot junction or sensing junction.

- The temperature difference produces a thermal emf which is measured by a potential or a digital voltmeter, the use of this thermal emf as a measure of temperature is known as thermocouple thermometry.
- The emf produced between the junction, causes a current to flow from hot junction to cold junction upto a certian maximum temperature.
- If the temperature of hot junction is increased beyond the maximum value then the current decreases & becomes zero at a particular temperature
- If the temperature of the hot junction is still increases, then the current reverses & increases
- Current produced in this way by heating junctions to different metals are known as thermoelectric current. These emf are called thermo emfs.
- The emf produced by a thermocouple is very small & is measured by a sensitive moving coil milli voltmeter
- The following combinations will give the thermo couple materials
  - Iron - Constantan
  - Copper - "

- Chromel (nickel-Chromium)
- Alumel (nickel-aluminium)
- Chromel -constantan
- Platinum rhodium-platinum.

- The materials used for thermocouple should have following properties.
  - The emf produced should not change rapidly with time.
  - High resistance to corrosion should not oxidize
  - The emf generated per degree should be large enough.
  - The couple should be used through a board range of temperature.
  - Cost should be less.

Application of thermocouples:-

- For measurement of temperature up to 1400°C
- In industrial applications
- In medical instrumentation
- In scientific research.

Bimetals or thermostats:-

- A bimetal is made of two metallic strips of unlike metals alloy with different coefficients or thermal expansion
- At a certain temperature the strip will bend &

actuate a switch or a lever of a switch.

- The bimetal can be heated directly or indirectly.
- When heated the element bends so that the metal with the greater coefficient of expansion is on the outside of the arc formed while that with smaller coefficient is on the inside.
- When cooled the element bends in the other direction.
- Alloys of iron & nickel with low coefficient of thermal expansion are used as one element of the bimetallic strip.
- The other element consists of materials having high value coefficient of thermal expansion i.e. iron, nickel, constantan, brass etc.
- Bimetallic strips are used in electrical apparatus & in devices such as relays & regulators.
- The bimetal element cuts off or regulates the supply voltage at the pre-determined value of the current or temperature.
- A bimetal relay (bimetal element) or release can be used for overload protection of electric motors or any electric circuit against overloading.

- To maintain a constant temperature in a heater, a bimetallic regulator may be used.
- Many bimetal devices are adjustable for a particular current. If the current rises above its setting value, the strip will be heated enough to bend & break the circuit either directly or through an intermediate relay.

Applications:-

- A bimetal relay can be used for overload protection of electric motors or any electric circuit.
- The bimetal element cuts off or regulates the supply voltage at the predetermined value of the current or temperature.
- Bimetallic strips are used in making relays, regulators etc.
- The common use of bimetal element is the protection of the electric motor or electric circuit against overload.

Application of bimetallic strip:-

- Geysers
- Automatic Iron box
- Thermal relays
- Regulators.

Soldering materials:-

- soldering is an process of two or more metals of low melting point which is used to join two or more pieces of metals
- The melting point of a solder is lower than the materials to be jointed.
- The molten metal joins the pieces of metals & the process is known as soldering.
- The most common solder is an alloy of tin & lea[d]
- The lead-tin solder serves to join copper, bron[ze], brass, tinned iron, zinc etc.

There are two types of solders

- Soft solders(melting point lower than 400°C)
- Hard solders(" higher than 400°C)

Soft solders:-

- Soft solders are composed of lead & tin in various proportions. The most important applications of soft solders is in electronic devices, coating of iron or steel sheets for roofing & filling of hollow casting etc.

Application:-

- Used in sheet metal work for joining parts
- Electronic devices
- " circuits
- Electrical appliances.

Hard solder:-

- A hard solder is an alloy of copper & zinc which is used for joining brass, copper, iron & steel

Fuse & Fuse materials:-

- A fuse is a protective device which consists of a thin wire or strip which melts when a particular value of current flowing through it is exceeded.
- Silver is costly hence it is commonly used as a fuse wire material but is used special type of fuses.

Dehydratic material:-

Silica gel:-

- It is inorganic chemical, colloidal, highly absorbent silica used as a dehumidifying & dehydrating agent, as a catalyst carrier & sometimes as a catalyst.
- Calcium chloride & silica gel are used in dehydrating breather to remove moisture from the air entering a transformer as it breaths