Conducting Materials

The materials which are used for conducting electricity are called conducting materials. They have normally low resistance value as compared to semiconducting and insulating materials.

Resistivity :-

Ohm's law :-

It states that, the potential difference existing across a circuit is directly proportional to the current flowing through the circuit, when temperature and pressure are maintained constant.

Mathematically,

$V \propto I$, temp^r and pressure constant.

$$\Rightarrow \boxed{V = RI}$$

$R \rightarrow$ proportionality constant $\rightarrow$ Resistance

Resistance is defined as the opposition to the flow of current.

unit :- ohm (Ω)

The resistance of any material is directly proportional to its length and inversely proportional to the cross sectional area of the material.

$R \propto \frac{l}{A}$

$\rho = \frac{RA}{L}$

$= \Omega m$

$$\boxed{R = \frac{\rho L}{A}}$$

ρ → Resistivity / specific resistance

where, 'R' is the Resistance of the material (Ω)

'ρ' is resistivity / specific resistance of the material (Ωm).

'L' is length of the material. (m)

'A' is area of cross section of the material (m^2).

Factors Affecting Resistivity :-

The different factors on which resistivity of a material depends are (i) temperature (°C)

(ii) Alloying

(iii) Mechanical Stressing

(i) Effect of Temperature :-

The change in resistance of a material per degree change in temperature per ohm is called temperature co-efficient of resistance of a material.

The change in resistance of a material w.r.t the change in temperature is given by the law

$$R_t = R_0 (1 + \alpha t)$$

where, 'R_t' is the resistance of the material at $t\,°C$.

'R_0' is the resistance of the material at $0\,°C$.

'α' is the temperature co-efficient of resistance.

't' is temperature in degree celcius.

Q. A coil of a relay is made of copper which has a resistance of 400 Ω at 20° C. Calculate the resistance of the coil at a temperature of 80°C. Temperature co-efficient of copper is 0.0038 Ω/°C at 0° C.

Sol

Given,

$R_{20} = 400\ \Omega$

$\alpha = 0.0038\ \Omega/°C$

$R_{80} = ?$

At $t = 20°C$, At $t = 80°C$

$R_{20} = R_0(1 + \alpha \cdot 20)$ — (1) $R_{80} = R_0(1 + \alpha\, 80)$ — (2)

$\Rightarrow 400 = R_0\left(1 + (0.0038)\,20\right)$

$\Rightarrow 400 = R_0 (1 + 0.076)$

$\Rightarrow 400 = R_0 (1.076)$

$\Rightarrow R_0 = \frac{400}{1.076}$

$= 371 \, \Omega$.

putting value of 'R_0' in eq^n (5)

$R_{80} = R_0 (1 + \alpha \cdot 80)$

$= 371 (1 + 80 (0.0038))$

$= 371 (1 + 0.304)$

$= 371 (1.304)$

$= 483.7 \, \Omega$.

$\simeq 484 \, \Omega$.

Q. The resistance of a wire increases from $40 \, \Omega$ at $20^\circ C$ to $50 \, \Omega$ at $70^\circ C$. Calculate the temperature co-efficient of resistance at $0^\circ C$.

Sol^n

Given,

At $t = 20°C$, $R_{20} = 40\ \Omega$

At $t = 70°C$, $R_{70} = 50\ \Omega$

$R_{20} = R_0(1 + 20\alpha)$

$\Rightarrow 40 = R_0(1 + 20\alpha)$

$\Rightarrow R_0 = \frac{40}{1 + 20\alpha}$ —(1)

$R_{70} = R_0(1 + 70\alpha)$

$\Rightarrow 50 = R_0(1 + 70\alpha)$

$\Rightarrow R_0 = \frac{50}{1 + 70\alpha}$ —(2)

Equating eq^n (1) and (2),

$\frac{40}{1 + 20\alpha} = \frac{50}{1 + 70\alpha}$

$\Rightarrow 40 + 2800\alpha = 50 + 1000\alpha$

$\Rightarrow 1800\alpha = 10$

$\Rightarrow \alpha = \frac{10}{1800}$

$\Rightarrow \alpha = \frac{1}{180} = 0.0055\ \Omega/°C$.

(II) Effect of Alloying :-

→ Alloying is the addition of impurities or some other metals to a material.

→ It increases the resistivity as well as the mechanical strength of the material.

(III) Effect of Mechanical stressing :-

→ The resistivity of a material changes under the influence of mechanical stressing which tends to harden the material and increases its tensile strength.

→ Mechanical stressing increases the resistivity of the material resulting in decrease of electrical conductivity.

Classification of conducting Materials :-

→ Low Resistivity Material.
→ High Resistivity material.

Low Resistivity Material :-

These low resistivity materials are used in housewiring, conductors for power transmission and distribution, winding of transformer and other machines.

The following properties of low resistivity materials are.

(1) Low temp. coefficient (α)

This means that change of resistance with change in temperature should be low. This is necessary to avoid variation in voltage drop and power loss due to change in temperature.

(2) Sufficient Mechanical Strength :-

The transmission line wire are subjected to mechanical stress due to wind and their own weight. so the conductor material should possess sufficient mechanical strength to withstand these mechanical stresses.

(3) Ductility :-

→ It is the property of a material which allows it to be drawn into a thin wire.

→ The conducting material should be ductile enough to be drawn into thin wires of different shapes and sizes.

(4) Solderability :-

The conducting materials need to be joined offering minimum contact resistance

(5) Resistance to corrosion :-

The conducting materials should be such that they are not easily corroded when exposed to atmosphere.

High Resistivity Materials :-

High Resistivity materials are used for making resistance elements for heating devices, starter in electric motors, resistance used in precision measuring instruments, Loading resistance, rheostats and filament for incandescent lamps.

The high resistivity material will possess the following properties.

(1) Low temperature coefficient (α) :-

→ The high resistivity materials should have negligible temperature co-efficient of resistance so that the accuracy of measurements will not be affected.

(2) High melting point :-

The high resistivity materials should be able to withstand high temperature for long time without melting.

(3) <u>No tendency for oxidation</u> :-

The high resistivity materials should be able to withstand high temperature without getting oxidised.

(4) <u>Ductility</u> :-

High resistance materials should be ductile to be drawn into wires of different shapes and sizes.

(5) <u>High mechanical strength</u> :-

The high resistivity materials should have larger tensile strength to withstand mechanical stress and to be drawn into different shapes and sizes.

Low resistivity materials and their applications :-

(1) Copper :-

Properties :-

→ It is reddish in colour and available in hard drawn or annealed form.

→ Copper is non-magnetic and its tensile strength varies from 8.15 to 4.72 tonnes/cm^2. (wt/A)

Application :-

→ Hard drawn copper is used in overhead conductors, High voltage underground cables and bus-bar.

→ Annealed copper is used for insulated cables in low-voltage lines, winding wire for electrical machines, flexible wires and in making coils.

(2) Silver :-

Properties :-

→ pure silver has high electrical conductivity and is corrosion resistance.

→ It has lower tensile strength.

Application :-

→ It is used for making brushes and collector ring of DC motor (silver-graphite alloy is used).

→ It is used for making commutator segment of DC motor (silver copper alloy is used).

(3) Gold :-

Properties :-

→ It is the best known electrical conductor.

→ It has good corrosion resistant property.

Use :-

→ Its alloy is used for making coins and jewellary and used as a brazing material.

→ It is used for making contact material in electrical field.

Aluminium :-

Properties :-

→ Alluminium is widely used electrical conductor which is much lighter than copper.

→ Its melting point is 655°C and has conductivity level just next to copper

Uses :-

→ It can be used as a substitute for copper in flexible wires, overhead transmission line, bus-bar, Induction motor rotor bars etc.

Steel :- (Iron + Carbon)

→ Steel contains Iron with a small percentage of carbon added to it.

→ The resistivity of steel is 8-9 times higher than copper.

→ Depending on the carbon content steels are classified into three types :-

(1) Mied carbon steel.

(2) Medi

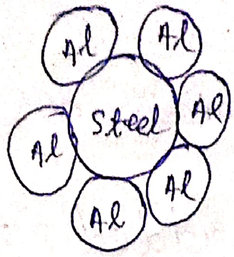
→ Containing 0.25 % carbon.

2) Medium steel containing 0.45 % carbon.

(3) High carbon steel contains 0.7 % carbon and higher.

ACSR :-

→ Aluminium conductor steel Reinforced.



Bundled

Stranded.

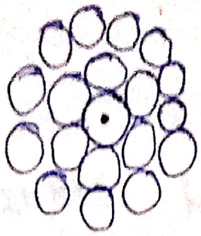
In this type of conductors the core conductor is made up of steel and reinforcement is done by Aluminium conductors on the periphery. steel reinforcement is done for giving higher strength to the overhead conductors used in the transmission lines.

<u>stranded conductors</u> :-

→ stranding is done by using a bunch of conductors to make the conductor flexible and avoid breakage.

→ It increases the power handling capacity.

→ A stranded conductor is made by twisting the wires in opposite direction for successive layers.



1, 6, 12 .

Total number of conductors is given by

$1 + 3n(1 + n)$

where n = no of layers.

Bundled conductors :-

→ In bundled conductors increased power transmission and current carrying capacity is achieved.

→ A fixed distance is allowed to remain in betn the conductors to avoid voltage stress and lower the Radio interference and corona loss.

Low Resistivity Copper Alloys :-

(1) Brass :-

→ when copper is alloyed with 40% zinc then it forms Brass. (Cu 60% + Zn 40%)

→ It has high tensile strength and low conductivity than copper.

Uses :-

→ used as current carrying and structural material in plug - point, socket outlet, switches, Lamp holder, Fuse holder, sliding contact for rheostats and starters.

(2) Bronze :-

Copper is alloyed with tin (8% - 16%) and some third element like cadmium, phosphorous, then it forms Bronze which possess high mechanical strength and low conductivity.

Uses :-

→ used for making current carrying springs, sliding contacts, knife - switch blades.

(3) Beryllium Copper alloy :-

Beryllium copper alloy is also called Bronze.

It has high conductivity and mechanical strength

Uses :-

→ used for making current carrying springs, brush holders, coil springs and knife switch blades.

High Resistivity Materials and their Applications :-

Tungsten, platinum, mercury, constantan, Manganin.

(1) Tungsten :-

→ Tungsten is a hard metal with resistivity twice that of Aluminium.

→ Its melting point is the highest of all metals i.e. 3300°C.

→ Its is highly ductile element with greater tensile strength.

Uses :-

→ It is used in incandescent lamps, heater in electron tubes, filament material in projectors etc.

(2) carbon :-

→ carbon has high value of resistivity, negative temperature co-efficient of resistance, pressure sensitive and low surface friction.

uses :-

(1) It is used for making brushes of electrical machines, electrodes for arc furnaces, carbon resistors, arc lamps etc.

(3) platinum :-

→ platinum is a greyish white metal.

→ It is non-corroding, malleable, ductile and is resistant to chemicals.

uses :-

→ It is used as a heating element in furnaces and laboratory ovens.

→ It is used as a contact material in thermocouples and special purpose vacuum tubes.

(4) Mercury :-

→ Mercury is a heavy silver white metal which remains as a liquid at room temperature.

Uses :-

→ It is used in mercury arc rectifiers, gas filled tubes and as a contact material in electrical switches.

Superconductivity :-

Superconductivity is the phenomenon in which the resistivity of the metals becomes zero when their temperature is brought near 0° Kelvin (-273 °C)

Superconductivity was discovered by Heike Kamerlingh Onnes in 1911 in mercury at 4.5 Kelvin.

Transition Temperature :-

The temperature at which transition takes place from the state of normal conductivity to superconductivity is called Transition Temperature

There are two types of superconducting materials.

Type - I superconductors and Type - II superconductors.

Type - I	Type - II
(I) Type - I superconductors are called soft superconductors with low critical temperature in the range of 0 K to 10 K.	(I) Type - II superconductors are called hard superconductors with high critical temperature in the range of > 10 K.
(II) Low critical magnetic field i.e. less than 1 Tesla.	(II) High critical magnetic field greater than 1 T.
(III) It perfectly obeys meissner's effect i.e. magnetic field can not penetrate inside the material.	(III) It does not obeys meissner's effect and magnetic field can penetrate inside the material.
(IV) Type - I superconductors are completely diamagnetic.	(IV) Type - II superconductors are not perfectly diamagnetic.

(v) They are also called low temperature superconductors and generally consists of pure metals. Ex :- Mercury, lead, zinc.	(v) They are high temperature superconductors which generally consists of alloys and complex oxide of ceramics; Ex :- Nb Ti, $Nb_3 Sn$

Application of superconductors :-

(1) Electrical Machines :-

Superconductors are being used in electrical machines and transformers to increase the conductivity range and machine efficiency.
Electrical machines employing superconductors can reach an efficiency level of 99.9 %.

(2) Power Cables :-

Superconducting materials are being used in power cables for transmission of power over long distances without any significant power loss.

(3) Electromagnet :-

Superconducting solenoids which do not produce any heat during the operation are being developed to be used as electromagnets.

(4) Future prospects :-

Superconductors are required to be maintained at extremely low temperature at around 0K. Depending on this low temperature requirement, the field of cryogenics is the new emerging technology.

SEMICONDUCTORS MATERIALS

Semiconductor :-

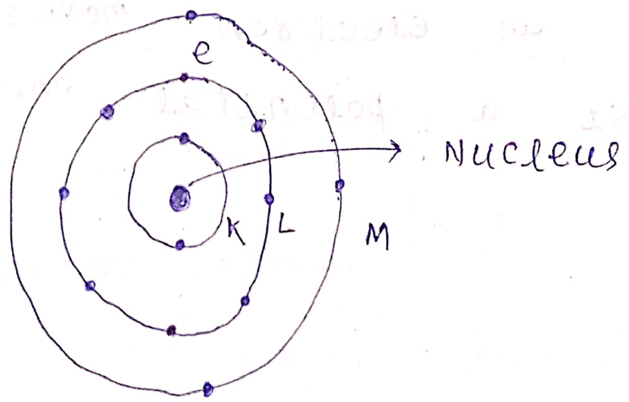
Semiconductor is neither a good conductor of electricity nor a good insulator. Its conductivity lies in between conductors and insulators.

The resistance of a semiconductor decreases with the increase in temperature.

Some typical examples of semiconducting materials are Germanium, Silicon, Arsenic, Gallium.

Electron Energy and Energy Band Theory :-

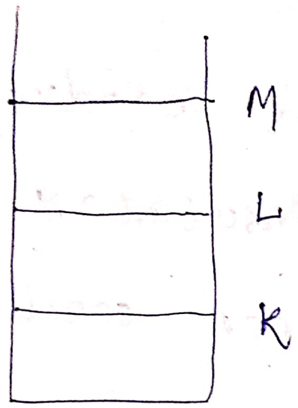
Bohr's Atomic Model :-



Al → 2, 8, 3 (13)

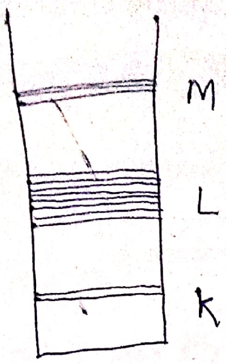
Typical atomic model of Aluminium

Simplified Representation of energy shells :-



An electron revolving around the nucleus of an atom has potential energy, centrifugal energy, Rotational energy and magnetic energy. These combined energies of an electron determine the total energy or energy level of an electron which is measured in electron-volts (eV).

The electron-volt is defined as that amount of energy gained or lost when an electron moves with or against a potential energy of 1 V.



Energy level of Al atom

Energy level in form of energy band

→ The larger the orbit in which an electron revolves, the greater is its energy.

→ Electrons with the least energy are on the K level i.e. the orbit closest to the nucleus.

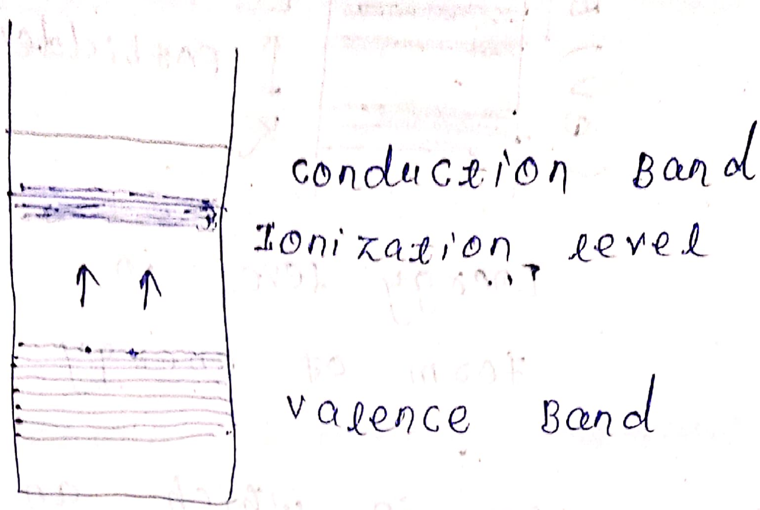
→ Each succeeding level contains ~~energies~~ electrons with higher energies.

→ No two electrons share exactly the same orbit and the energies of electrons is never same.

→ The energy levels are grouped into energy bands. The gap between the energy bands is called Forbidden zone. (since no electron shares its energy level in these areas so it is called

Forbidden zone.

Excitation of Atoms :-

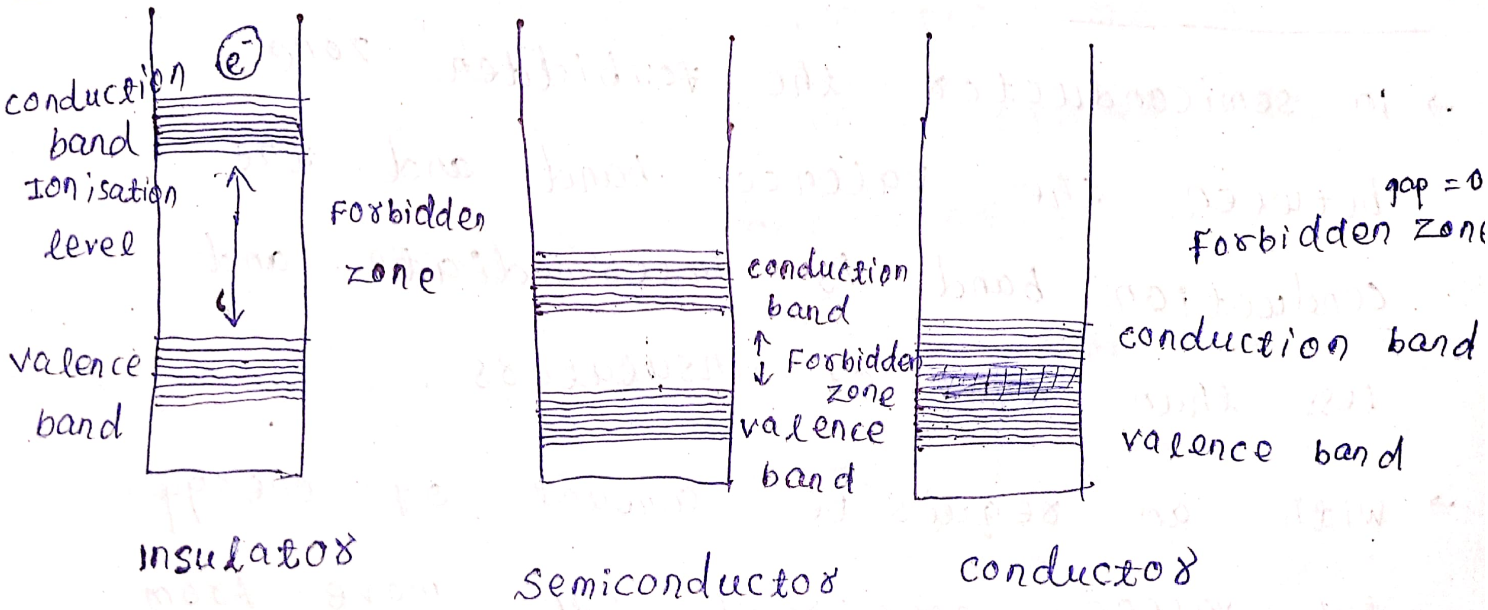


When each electron in an atom is in its normal state and normal energy level, then the atom is said to be in its unexcited state.

When the electron is in the higher energy level, the atom is said to be in the excited state. To move an electron from the normal ground state to higher energy level requires additional energy in the form of light, heat, electrostatic, magnetic, kinetic.

when the required amount of energy is absorbed by a valence electron, it will leave the valence band and move towards the ionization level. An electron above the ionisation level is said to be in the conduction band and is called a free electron. The electron in the conduction band is no longer neutral and carries a charge and is said to be ionized.

Difference between Insulators, Semiconductors and conductors :-



Insulator :-

→ In insulators the forbidden zone between the valence band and the conduction band is quite large and the valence electrons are tightly bound to the nucleus of the atom.

→ A high amount of energy is needed to release the valence electrons from the valence band. So conduction is not feasible in an insulator.

Ex :- wood, paper, paraffin wax etc.

Semiconductor :-

→ In semiconductor the forbidden zone between the valence band and the conduction band is intermediate and less than that of insulators.

→ With an requisite amount of energy the valence electrons can move from the valence band to the conduction band. So conduction is possible in semiconductors.

Ex :- Germanium (Ge), silicon (Si), Arsenic (Ar) etc.

conductors :-

→ In conductors the valence band and the conduction band overlap each other and the forbidden zone is negligible.

→ The electrons from the valence band can move to the conduction band with very less amount of energy.

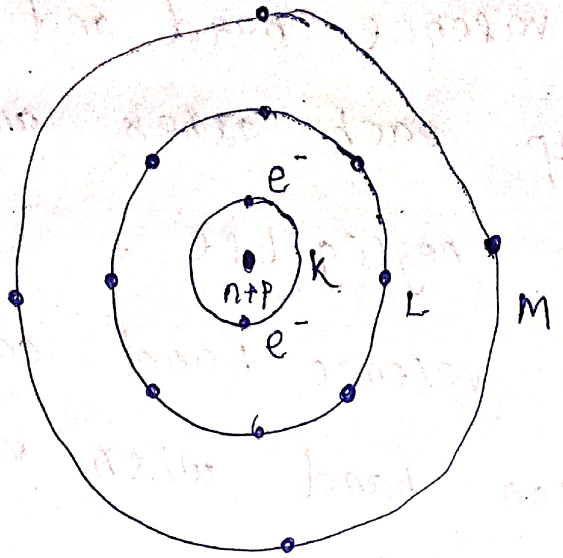
→ So conductors are the optimum conducting materials that conduct electricity easily.

Ex :- Gold, silver, copper, Aluminium.

Semiconductor Materials :-

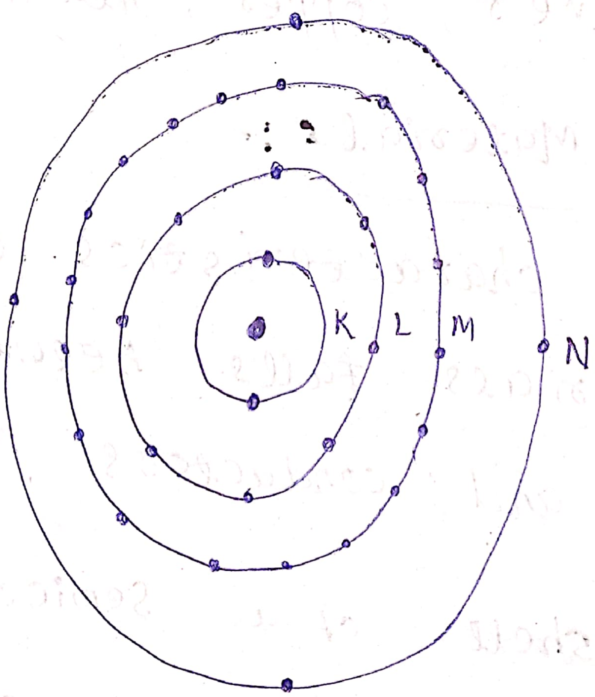
→ The electrical characteristics of semi-conductor materials falls between those of insulators and conductors.

→ The valence shell of a semiconductor has four valence electrons as compared to that of 8 valence electrons for best insulators and 1 valence electron for best conductors.



Si (14 atomic number)

(2, 8, 4)



Ge (32 atomic number)

(2, 8, 18, 4)

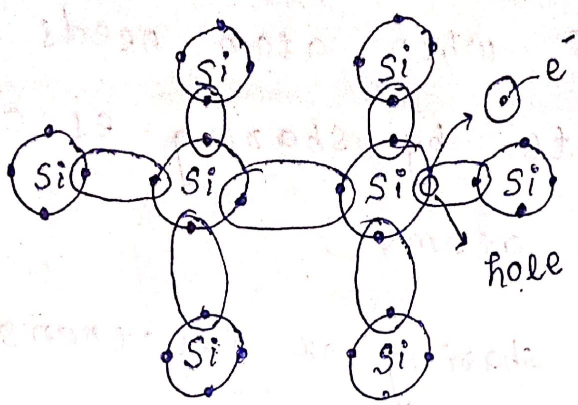
Covalent Bond :-

→ A covalent Bond forms when atom needs to attain its octet state by sharing electrons with the neighbouring atoms.

→ The bond formed by sharing of electrons does not gives a perfect crystal structure to the semiconductor materials.

Intrinsic semiconductors :-

An intrinsic semiconductor does not contains any impurity atoms and is pure in form. When an electron is freed from an intrinsic material it breaks a covalent bond and leaves behind a vacancy called hole. The electron hole pair in an intrinsic semiconductor leads to the conducting capacity of semiconductors.



→ The conductivity of intrinsic semiconductor depends on the value of applied voltage and temperature.

→ With the rise in temperature the electron - hole pairs are generated in larger quantity, subsequently increasing the conductivity of semiconductors.

The temperature rise causes decrease in the value of resistivity.

→ So intrinsic semiconductors has negative temperature co-efficient of resistance.

Extrinsic Semiconductors :- (doping - add' of impurity)

In extrinsic semiconductor, the semiconductor material is doped with external impurities to increase the conductivity level of semiconductors.

→ The extent to which an impurity has been added is called the doping level.

Types of extrinsic semiconductor :-

(1) N - type material

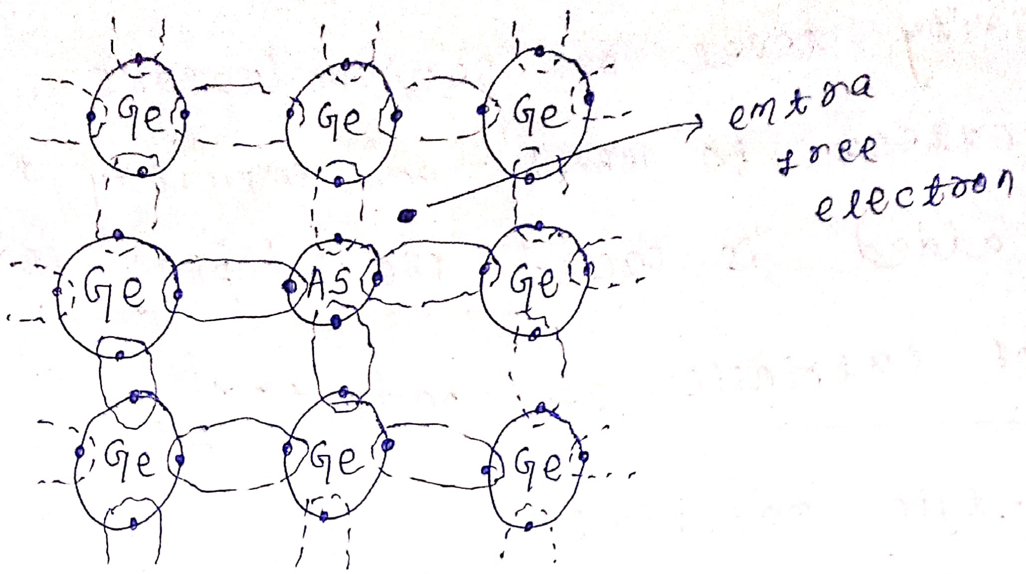
(2) P - type material

(1) N-type material :-

→ In N - type material pentavalent impurities are added to the intrinsic semiconductor.

→ The pentavalent impurities are arsenic, phosphorous, Antimony.

→ When pentavalent impurity is added it donates an extra electron and are called the donor impurities. due to the excess of electrons this type of material is called N - type material (N - stands for negative).

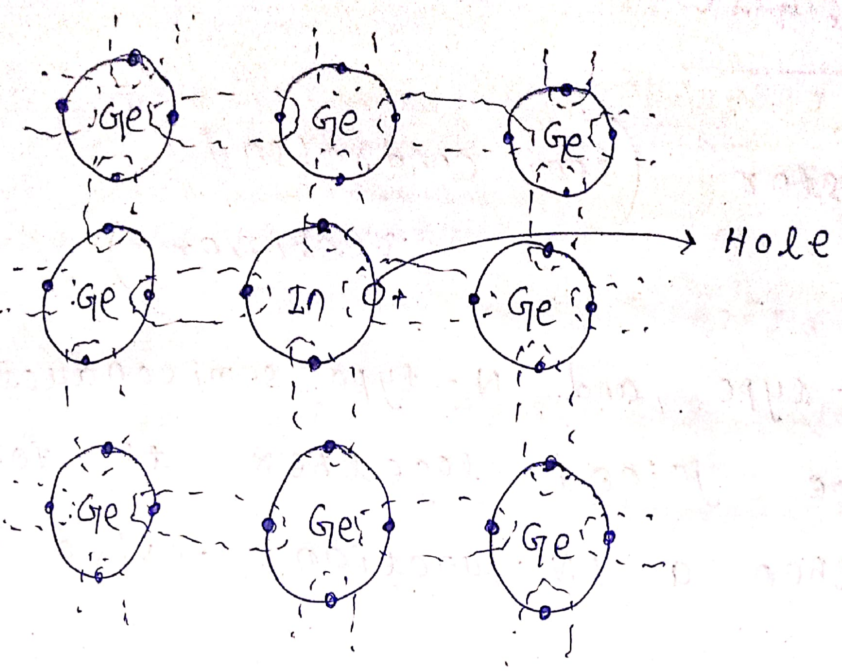


P-type Material :-

→ In P-type material trivalent impurities are added to the intrinsic semiconductor.

→ The trivalent impurities are gallium, Indium, Aluminium. when trivalent impurities are added it requires an extra electron to complete the covalent bond sharing with neighbouring atoms due to shortage of an electron, a hole is created in its space to complete the bond formation.

→ These impurities are called acceptor impurities and the materials are called p-type material (P → positive).



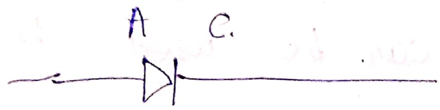
majority and minority carries :-

→ In N type material electrons are the majority carriers and holes are the minority carriers.

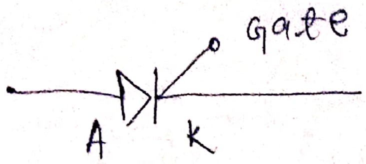
→ In p type materials holes are the majority carriers and electrons are the minority carriers.

Applications of semiconductor materials :-

(1) Rectifiers :- (AC → DC) (- Inverter DC → AC)



Diode (uncontrolled rectifier)

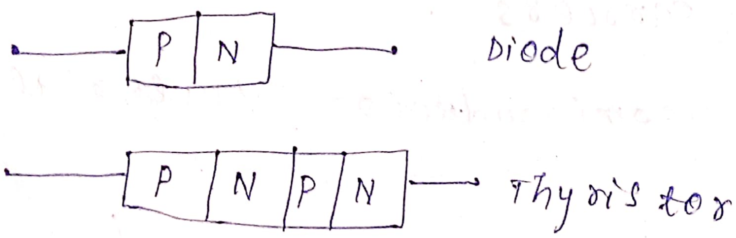


Thyristor (semi controlled rectifier)

→ When a P-type and N-type semiconductor material are joined together to form a junction, then a PN-junction device is formed.

→ For a diode P-side of the PN junction forms the anode and N side forms the cathode. When diode is forward-biased, it conducts only in one direction.

→ A thyristor is a three terminal semiconductor device (Anode, cathode and Gate) with 3 PN junctions.



Thyristor is a silicon controlled rectifier (SCR) with high PIV rating (Peak inverse voltage rating) and can be used in semicontrolled way for ac to DC rectification.

(2) Temperature sensitive resistors :- (Thermistors)

Increasing the temperature of semiconductor material decreases their resistance. This property is used in devices called Thermistors which are temperature sensitive resistors.

They find application in temperature measurement and control, measurement of radio frequency, power, voltage-regulation and in timing and delay circuits.

(3) Photoconductive cells :-

~~Photo conduct~~ The resistance of semiconductor material is low under light and increases in darkness. This phenomenon is used in photo conductive cells which are used in door-openers, burglar alarms, flame detectors, smoke detectors and control of street lights.

(4) Photovoltaic cells :-

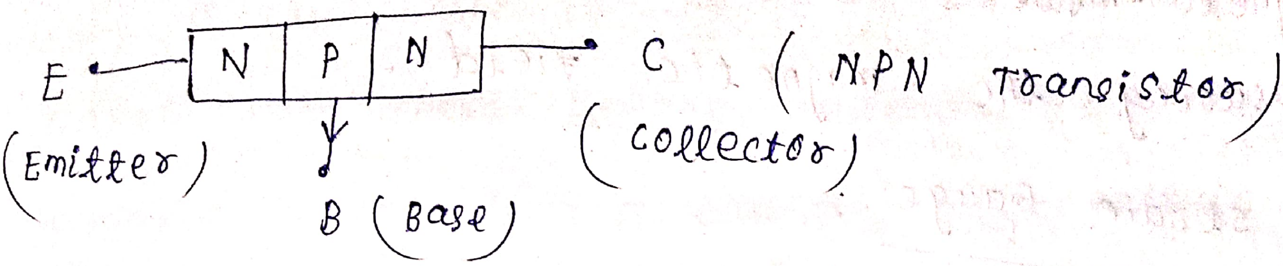
Photovoltaic cells are the devices that develop emf when illuminated. This property to convert light energy directly into electrical energy is called photovoltaic effect and is used in solar cells to produce electricity.

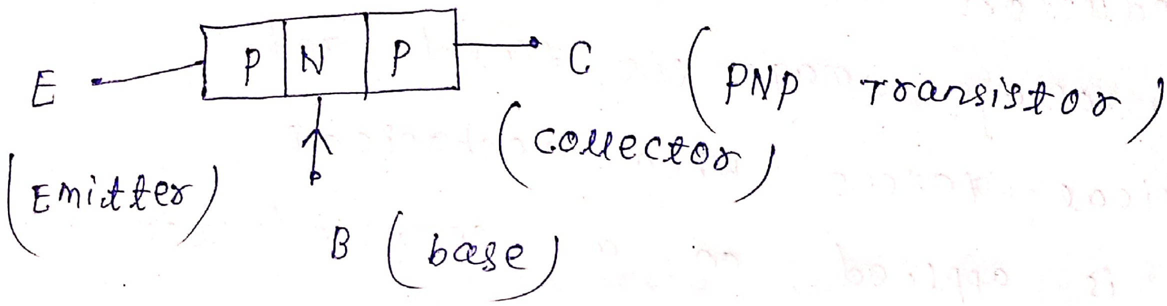
(5) Varistors :-

The resistance of semiconductors can be varied by adjusting the applied voltage. This property is used in devices called varistors that find application in voltage stabilization, motor speed control and voltage dependant resistors.

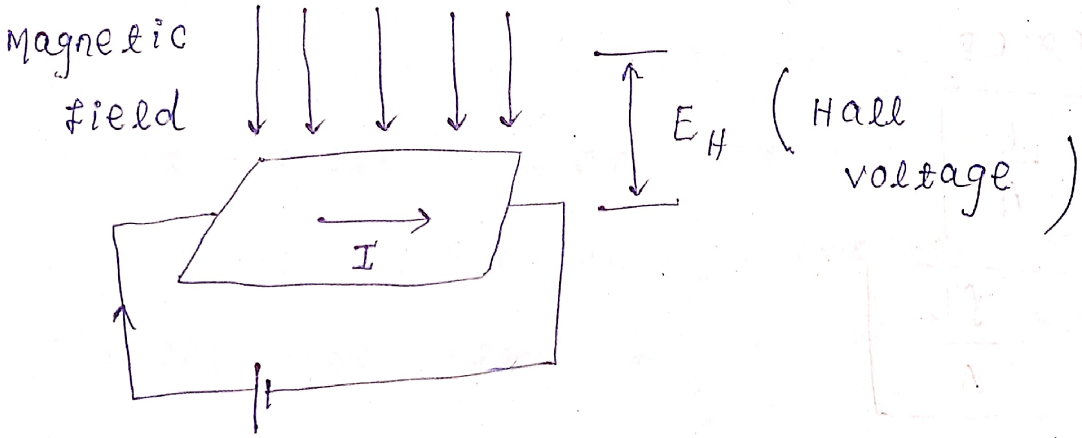
(6) Transistor :-

Transistor is a two junction, three terminal semiconductor device used for controlling the current in a circuit or for voltage amplification and other switching circuit. voltage applied to one pair of terminals of transistor can control the current through another pair of terminals.





(7) Hall Effect Generator :-



When current flows through a semiconductor bar placed in a magnetic field, a voltage is developed at right angles to both current and magnetic field. This voltage is ~~perpendicular~~ ~~proportional~~ proportional to both current and the intensity of magnetic field. This phenomena is called Hall efect.

Hall - effect generators are also called magneto-meters which are used for measuring the magnetic field.

(8) Strain Gauge :-

Semiconductors are sensitive to heat, light, voltage, magnetic field and mechanical forces. When mechanical force is applied on a semiconductor bar its length increases thereby increasing the forbidden zone and the resistivity of the material increases.

$$R \propto \frac{l}{A}$$

$$\Rightarrow R = \frac{\rho L}{A}$$

Strain gauges are use to test the tensile strength of materials and in determining the change in length of structures.

(9) solar power :-

Sun is the ultimate source of energy on Earth. The conversion of solar energy into electrical energy is called photovoltaic effect.

Solar cell is the photovoltaic device that directly converts solar energy into electrical energy. Solar cell is a PN-junction device with large surface area. When solar energy falls on the surface of solar cell electrons starts flowing from the N-plate to the P-plate by means of photo emission process. This gives rise to potential difference and constitutes the flow of electric current.

Solar cells are used in watches, calculators, solar water heat, solar pump and space research work.

Insulating Materials

The material which prevents the flow of electricity through them are called insulating materials. They have very high resistance and can be used to insulate the conducting part.

General properties of Insulating Material :-

The different properties of insulating material taken into consideration are

(1) Electrical properties.
(2) visual properties.
(3) mechanical properties.
(4) Thermal properties.
(5) chemical properties.

(1) Electrical properties :-

(a) Insulation resistance :-

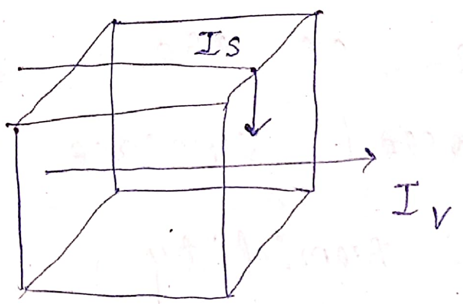
This is the property of an insulator by virtue of which a material resists the flow of electric current. For an insulator if 'V' is the applied voltage and 'I' is the current flowing through it then insulation resistance is given by $R = \frac{V}{I}$

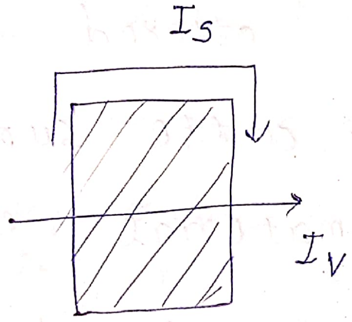
insulation resistance is very high and can be divided into two types.

(i) volume resistance

(ii) surface resistance.

(i) volume resistance :-





The resistance offered to current Iv flowing through a material is called volume resistance. The resistivity is defined as the resistance offered to the flow of current through the body of the material. volume resistance is expressed as,

$$R_V = \rho_V \frac{l}{a}$$

'ρ_v' is the volume resistivity expressed in ohm-meter (Ω-m).

'l' is the length of the current path through the material in meter,

'a' is the cross sectional area of the current path in m^2.

(ii) Surface Resistance :-

The resistance offered to current I_s flowing on the surface of the insulating material is called surface resistance. It depends on humidity.

Factors Affecting Insulation Resistance :-

(i) Insulation resistance depends on temperature variation.

(ii) Exposure to moisture decreases the value of surface resistance.

(iii) Insulation resistance is also affected by the applied voltage.

(iv) The resistance of insulating material decreases with age.

(v) presence of impurities in the material decreases the value of insulation resistance.

(b) Dielectric strength :-

Dielectric strength is the minimum voltage which when applied to an insulating material results in the destruction of the insulating properties. (Mica maximum)

or,

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

Unit :- KV/mm or V/mm.

Factors affecting Dielectric Strength :-

(I) Dielectric strength decreases with the rise in temperature (II) Humidity decreases the value of dielectric strength.

Dielectric Constant :-

→ Insulating material has the property of storing charge when voltage is applied across them.

→ The charge stored is proportional to the applied voltage which is given by

$Q \propto V$

$\Rightarrow$ $Q = CV$

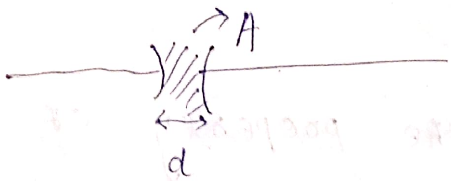
Where, 'c' is the proportionality constant, called capacitance of the material.

The property of the insulating material that causes difference in the value of capacitance keeping the physical dimension constant is called dielectric constant or permittivity.

$$C \propto \frac{A}{d}$$

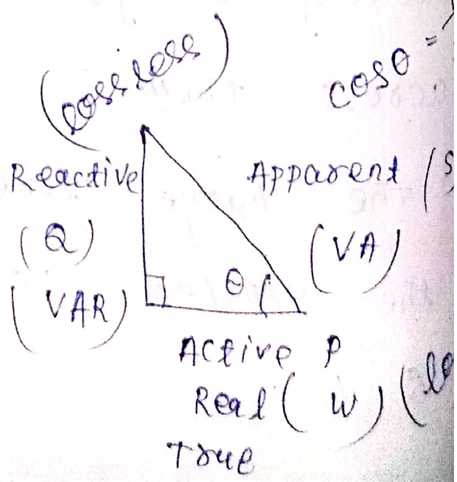
$$\Rightarrow \boxed{C = \frac{\epsilon_0 A}{d}}$$

Where, 'A' is the cross sectional area of insulation and 'd' is the distance between the two plates.



Dielectric constant of the material is given by,

$$\boxed{\epsilon = \epsilon_r \epsilon_0}$$



where, 'ϵ' is the dielectric constant of the material.

'ϵ_r' is the relative dielectric constant or relative permittivity.

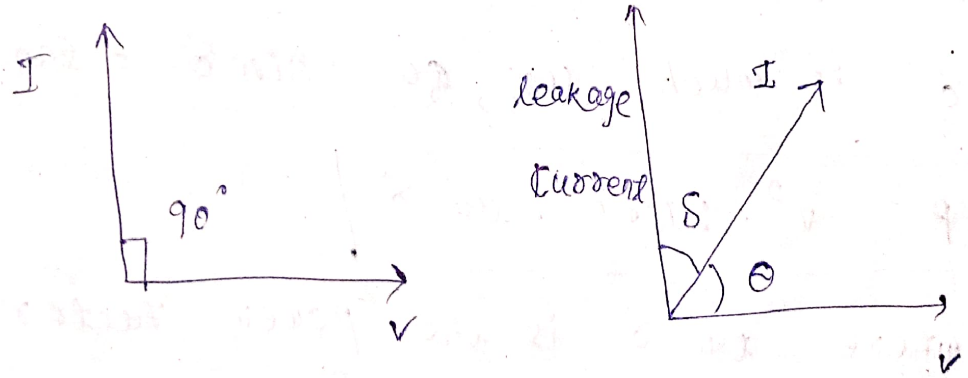
'ϵ_0' is the dielectric constant of air/vacuum.

Maximum of water (80)

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

Dielectric loss :-

when a perfect insulator is subjected to alternating voltage it behaves as a perfect capacitor. Normally all dielectrics does not behaves as pure capacitors and there is a significant power loss. This dissipation of energy is called dielectric loss.



δ → dielectric loss angle.

pure capacitor

$$P = VI \cos\theta$$

$$= VI \cos 90^\circ$$

$$= 0$$

$$P = VI \cos\theta$$

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

$$= \frac{V^2}{X} \cos\theta$$

$$= \frac{V^2}{X} \cos(90^\circ - \delta)$$

$$= \frac{V^2}{X} \sin\delta$$

$$\boxed{P = V^2 \cdot 2\pi f C \cdot \sin\delta} \quad \left[\because X = \frac{1}{2\pi f C}\right]$$

power loss in dielectric

~~$P = V^2 \cdot 2\pi f C \cdot \tan\delta$~~

since 'δ' is much less, so $\sin\delta = \tan\delta$

$$\boxed{P = V^2 \cdot 2\pi f C \cdot \tan\delta}$$

where $\tan\delta$ is the power factor of the insulator.

Dielectric loss depends on the following factors.

(i) Dielectric loss increases proportionately with the increase in frequency of applied voltage.

(ii) Dielectric loss increases with the presence of humidity.

(iii) Dielectric loss rises with the increase in temperature.

(iv) Increase in the value of applied voltage increases the dielectric loss.

(2) Visual properties :-

The visual property of an insulating material includes colour, Appearance, crystallinity.

This properties find importance from the performance point of view.

(3) Mechanical properties :-

The mechanical properties considered for selection of insulating materials are

(a) Mechanical strength :-

Most solid insulators are required to withstand various loads during manufacturing and operation. The mechanical strength depends on various factors like temperature rise and climatic effects.

→ Insulating materials are subjected to different types of mechanical stress like tension, compression, resistance to abrasion, tear, shear and impact.

(b) porosity :-

High porosity insulating materials increases the moisture holding capacity and affects the electrical properties, so it is not desired for an insulating material to have high porosity.

(c) viscousity :-

viscousity is the properties of liquid dielectrics that determines the adhesivity of liquid dielectric.

→ It affects the manufacturing process and this process is use to purify the insulating oil used in transformers.

(d) solubility :-

→ Liquid dielectrics should be soluble in appropriate solvents to form useful for applications.

→ varnish is dissolved in acetone to form insulating varnish which is used in paints and enamels.

(e) Machinability and mouldability :-

This properties are important from mass production view point.

(4) Thermal properties :-

The thermal properties of insulating material taken into consideration are

(a) Melting point, Flash point and volatility :-

→ Melting point assumes importance in non-draining compound insulated cables.

→ Flash points impose restriction in manufacturing process to avoid possible hazards of apparatus catching fire.

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

(b). Thermal conductivity :-

The heat generated due to i^2R loss and dielectric loss will be dissipated through the insulator. An insulator with better thermal conductivity will not allow temp^r rise. This property is used in high voltage apparatus where the thickness of insulation is more.

(c) Thermal Expansion :-

Insulators with high co-efficient of thermal expansion undergo repeated cycles of expansion and contraction during load changes. So insulators with low co-efficient of expansion are used to avoid insulation breakdown.

(d) Heat Resistance :

The insulating materials should be able to withstand temperature variation within desirable limits without damaging other important properties. Insulators capable of withstanding high temperature without deteriotation are used in operations involving high temperature.

(e) Effect of temperature rise on life of an insulator :-

→ The operating temperature has a bearing on the life of concerned apparatus.

→ A tempr rise of 8°C - 10°C on the recommended operating tempr of a given apparatus halves the life span of an insulator.

(5) Chemical properties :-

(a) Chemical Resistance :-

The presence of gases, acids, alkali and salts affects the insulators differently. Insulators with better resistance to these chemical substances are used in various high voltage applications.

(b) Hygroscopicity :-

→ During manufacturing and operation of insulating materials they come in contant with atmosphere and moisture. The presence of moisture makes the humid atmosphere affect the insulation on the surface and on the body which affects the electrical properties of the insulator.

→ Some non-hygroscopic insulators are Paraffin, Polythene, P.T.F.E (Poly Tetra Fluoro Ethylene).

(c) Effect of Contact with other Materials :-

→ Insulation remains intact when coming in contact with other materials and elements.

→ Insulating oil when used in transformers reacts with the inner wall of the tank causing the iron particles to mix with the oil. This affects the insulating properties of oil.

Insulating Materials : characteristics, properties, Applications :-

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Classification of Insulating materials on the basis of physical and chemical structure :-

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(1) Fibrous materials.
(2) Impregnated fibrous materials.
(3) Non-resinous materials.
(4) Insulating liquid
(5) ceramics
(6) Mica and Mica products
(7) Asbestos and Asbestos products.
(8) Glass
(9) Natural and synthetic rubber.
(10) Insulating resins and their products
(11) Laminates, Adhesives, Enamels and varnish.

(1) Fibrous materials :-

Fibrous materials are derived from animal origin or from cellulose which is the major constituent of plants. The different fibrous materials are

(a) wood :-

wood is used in low voltage installations due to light weight and low relative density. It is hydroscopic in nature which in term reduces the mechanical strength. It is used as structural material for transmission and distribution poles.

(b) paper and CardBoard :-

The base material for manufacturing insulating papers is coniferous wood. The process of manufacturing paper from wood is called sulphate process.

paper insulation in impregnated form is used in apparatus for generation, transmission and utilization of electrical power. paper has good mechanical strength, ability to withstand high temperature, Low dielectric loss, ease of wrapping around the conductor; easy availability and cheapness.

Impregnated paper is used in telephone cables and capacitors.

(c) Insulating textiles :-

Textiles are made from fibrous materials like cotton, Jute, Hemp. These insulating textiles are mechanically strong in tensile and tear strength. They have improved properties like high mechanical strength, heat resistance, low hydroscopicity, stable in the presence of chemical agents.

(d) Cotton :-

It is made in the form of fibre or cloth and tapes for promoting insulation. It is porous, hygroscopic, flexible, low dielectric strength and gets easily carbonised.

It is used for winding of small and medium size machines, chokes and small transformer coils.

(e) Silk :-

It is a protein fibre consisting of long chain structure and is a poor conductor of heat.

Natural silk is used in instrument meters and other measuring instruments.

(f) Jute :-

It is made from cellulose and its fibres are thicker and cheaper in cost.

(2) Impregnated Fibrous Materials :-

Impregnation of fibrous materials is done to improve hygroscopicity, thermal and chemical properties

(a) Impregnated paper Dielectric :-

In paper dielectrics impregnation is done with oils after proper selection depending on the requirement. The features of impregnated paper dielectrics are good mechanical properties, good chemical stability, ability to withstand high tempr, Dielectric cons. betn 2.25 - 6.35 and non-inflamable.

~~(b) varnished or Imp~~

Uses :-

→ It is used in cables i.e. underground power cables, mining cables and submarine cables in the operating range of 220 V to 440 KV.

→ It is also used in high voltage power transformers and capacitors.

(b) Varnished or Impregnated Textiles :-

→ Two types of varnishes are impregnated with the textiles

(i) oil varnished

(ii) Olebituminous varnish

varnish belongs to class 'A' insulating materials.

varnished textiles have good mechanical strength, good dielectric strength, low hygroscopicity, low resistance to organic solvents.

Uses :-

→ It is used in windings of low and medium rating machines.

→ It is used in cables as wrappers.

and liners.

(3) Non-Resinous Materials :-

Non resinous materials are available in nature in organic form which includes mineral waxes, Asphalt, bitumens and chlorinated napthalin.

The non-resinous materials are classified into bitumens and waxes.

(i) Bitumens :-

These are solid or semisolids materials obtained by refining crude petroleum. The properties of bitumens are highley soluble in mineral and synthetic oil easily oxidised, resistant to moisture penetration, poor insulating property, acid and alkali resistant.

Uses :-

→ It is used in underground cables for protection of lead and steal armour against corrosion.

→ In underground cables it is used to provide bedding and serving of steal armour.

(ii) wax :-

waxes are of two types,

(a) paraffin and macrocrystalline wax.

(b) Natural wax.

(a) paraffin and macrocrystalline wax :-

These waxes are obtained by distillation of mineral petroleum oil. waxes are easily soluble in synthetic insulating oils, mechanically weak and have poor electrical properties.

uses :-

→ These are used for making non-draining impregnated compounds.

→ It is used for making MIND (mass impregnated Non-draining) paper cables.

(b) Natural wax :-

These are obtained from nature and have dielectric constant in the range of 2-3. They have lower electrical properties.

Uses :-

These are used as a constituent of sealing compound.

Dielectric Materials :-

The materials which are used for storing of electrical energy are called dielectric materials. Dielectric materials are insulating in nature with energy storing as the main functionality.

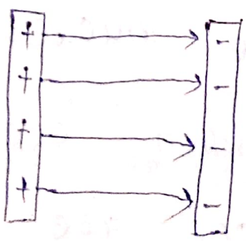
Dielectric constant :-

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

$$\epsilon = \frac{C}{C_o}$$

Polarisation :-

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



Electric field between the plate of a capacitor.

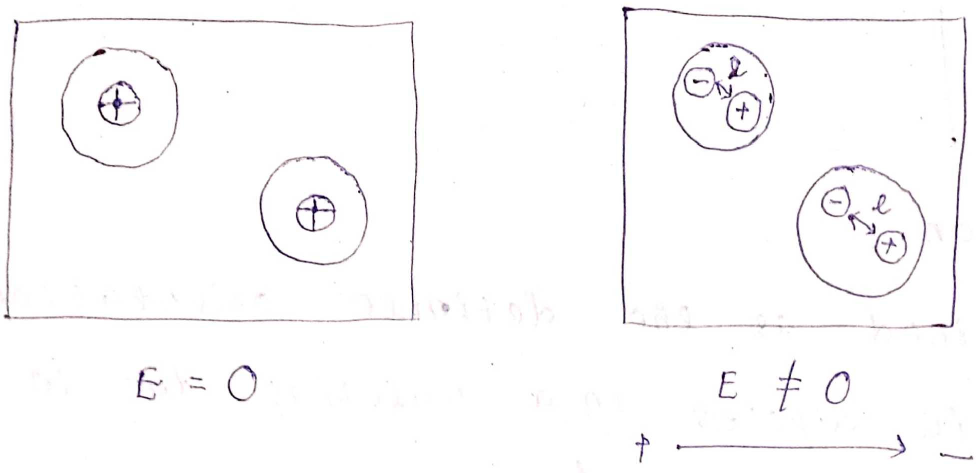
When a dielectric material is introduced between the two plates of a capacitor it is observed that the intensity of electric field and the potential difference existing betⁿ the charged plates gets reduced due to polarisation.

The better the dielectric more will be the value of / effect of polarization.

The dielectric molecules are classified into two types.

(1) Non-polar molecules
(2) polar molecules

(1) <u>Non-polar molecules</u> :-



E = 0 E ≠ 0

A non-polar molecule is one in which the centre of gravity of positive nuclei and electrons normally coinside. when electric field is applied, the electrons are attracted by the positive charge of the electron and are repelled by the negative charge of the second electron. The electronic displacement bet^n the electrons and the positive charges within an atom is called electronic polarisation.

Dipole moment :-

The product of elementary charge and the distance of separation between the charges is called dipole moment.

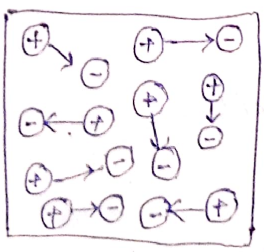
Mathematically it is given as

$$M = q \cdot l$$

where, q = elementary charge of particle

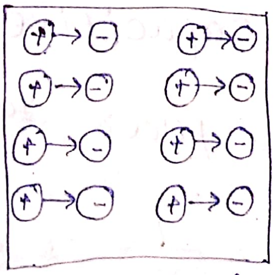
l = distance of separation between the opposite charges.

Polar Molecules / Dielectric :-



E = 0

orientation of polar dielectrics in the absence of electric field



(-) ← (+)

E ≠ 0

Definite orientation of electric dipoles in the presence of electric

Polar dielectrics are those dielectrics whose molecules possess permanent electric dipoles even in the absence of electric field. such molecules have centres of positive and negative charges displaced w.r.t each other and forms a dipole.

In the absence of electric field the dipoles are oriented in random fashion in the presence of externally applied electric field the dipoles orient themselves in the direction of electric field. The stronger the applied field, greater will be the number of dipoles orienting themselves in the direction of applied field.

Dielectric loss :~

$$P_{loss} = V^2 . 2\pi f C . \tan\delta .$$

P_{loss} = power loss.

V = applied voltage.

X_C = capacitive reactance.

$\tan\delta$ = power factor of dielectric.

$2\pi f C = \frac{1}{X_C}$ = susceptance (capacitive admittance)

In electronic polarisation the electrons undergo little displacement on the application of electric field. When the applied electric field is withdrawn the electrons return to their original position. This method of polarisation is completely elastic in nature giving rise to reactive current and there will be no dielectric power loss involved.

In ~~non~~ polar molecules the orientation of dipoles in the presence of externally applied electric field is not a completely elastic process. So in overcoming internal frictional force some amount of energy is wasted as heat in dielectrics. This wastage of energy in dielectrics is known as dielectric loss.

Electrical conductivity of dielectrics and their breakdown :-

(1) Gaseous Dielectric :-

Under the influence of electric field the free charges gets a directed motion in the direction of electric field giving rise to leakage current. As the electric field is increased more the random motion of the charges increases and they collide with other neutral charges.

Each newly freed electron gets accelerated to a very high speed due to applied electric field which in term knocks out another electron and the process of ionisation continues. This process is called ionisation by collision and the voltage at which this sudden increase in leakage current takes place in gaseous dielectrics is called breakdown voltage.

(2) Liquid Dielectrics :-

The liquid dielectrics gets easily contaminated with impurities that gives rise to impurity conductivity. On the application of electric field the liquid dielectrics get dissociated. Dissociation of molecules gives rise to conductivity. So in liquid dielectrics the presence of contaminants increases the conductivity under the application of an applied electric field. A breakdown in contaminated liquid leads to formation of conductive bridges between the electrodes by the contaminants in the inter electrode space by the applied electric field.

Acceleration of the process of ionisation results in the ultimate breakdown of liquid dielectrics.

(3) Solid Dielectrics :-

Electrical conductivity of solid dielectrics can be ionic, electronic or both in nature. Breakdown in solid dielectrics can be either electrothermal or electrical depending on the prevailing conditions.

Electrothermal breakdown is caused by the destruction of dielectric due to heat produced by dielectric loss. With the increase in temp^r the dielectric loss increases very rapidly causing breakdown of solid dielectrics.

Properties of Dielectrics :-

The general properties of dielectrics are,

(i) dielectric constant (water maximum → 70, air minimum → 1)

(ii) dielectric strength (maximum → mica 40 kV/mm, minimum → Asbestos 2 kV/mm)

(iii) power factor of electric (tan δ)

~~porcelain~~

minimum paraffin wax → 0.0003

maximum Impregnated paper → 0.06

(iv) maximum working temperature

minimum paraffin wax → 35°C

maximum porcelain → 1000°C

(v) relative density

max. Ebonite → 14

air minimum → 0.0013

Applications of Dielectrics :-

→ The most common application of dielectrics is for storing energy in capacitors.

→ capacitors are generally Grouped into the following types.

(1) capacitors that use air, vacuum or other gaseous dielectrics.

(2) capacitors that use mineral oil as dielectric.

(3) capacitors that use combination of solid and liquid dielectrics i.e. paper, mica, Glass etc and mineral oil, silicon etc.

(4) capacitors with only solid dielectric like Glass, mica, Titanium oxide etc.

Note
Electrolytic capacitors are the fixed value capacitors having high capacitance value used for bypass, coupling and motor starting applications.

Magnetic Materials :

→ The materials which can be magnetised are called magnetic materials.

→ The magnetic materials have a property called permeability by virtue of which it allows itself to be magnetised.

$$\mu = \mu_0 \mu_r$$

where, 'μ' is the permeability of the solid material.

'μ_0' is the permeability of free space or air with value $\mu_0 = 4\pi \times 10^{-7}$.

'μ_r' is the relative permeability of the material.

The magnetic flux density of a material is related to the magnetic field intensity by the formula,

$$B = \mu_0 H \Rightarrow B = \mu H$$

→ The magnetisation of a magnetic material results from the allignment of magnetic dipoles parallel to the applied magnetic field intensity.

$M \propto H$

$$\Rightarrow \boxed{M = \chi H}$$

where, χ is magnetic susceptibility.

$B = \mu_0 H$

$\Rightarrow B = \mu_0 (H + M)$

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

$\Rightarrow B = \mu_0 H \underbrace{(1 + \chi)}_{\mu_r}$

$\Rightarrow B = \mu_0 \mu_r H$

$$\Rightarrow \boxed{B = \mu H}$$

Classification of Magnetic Materials :-

Depending on the response of the materials towards the external magnetic field, magnetic materials are classified into three types.

(1) Diamagnetic material.

(2) paramagnetic material.

(3) Ferromagnetic material.

(1) Diamagnetic Materials :-

→ The magnetic materials in which permanent magnetic dipoles are absent are called diamagnetic materials.

→ When an external magnetic field is applied to the diamagnetic material, it induces a magnetisation in the opposite direction to the applied field intensity. So the relative permeability of the diamagnetic material is negative. $\mu_r = -ve$

(2) Paramagnetic materials :-

→ The magnetic materials which have small but positive relative permeability are called paramagnetic materials.

→ The magnetic dipoles are oriented in random fashion. On application of external magnetic field, the permanent magnetic dipoles orient themselves parallel to the applied magnetic field, giving rise to positive magnetisation. $\mu_r = +ve < 1$

(3) Ferromagnetic materials :-

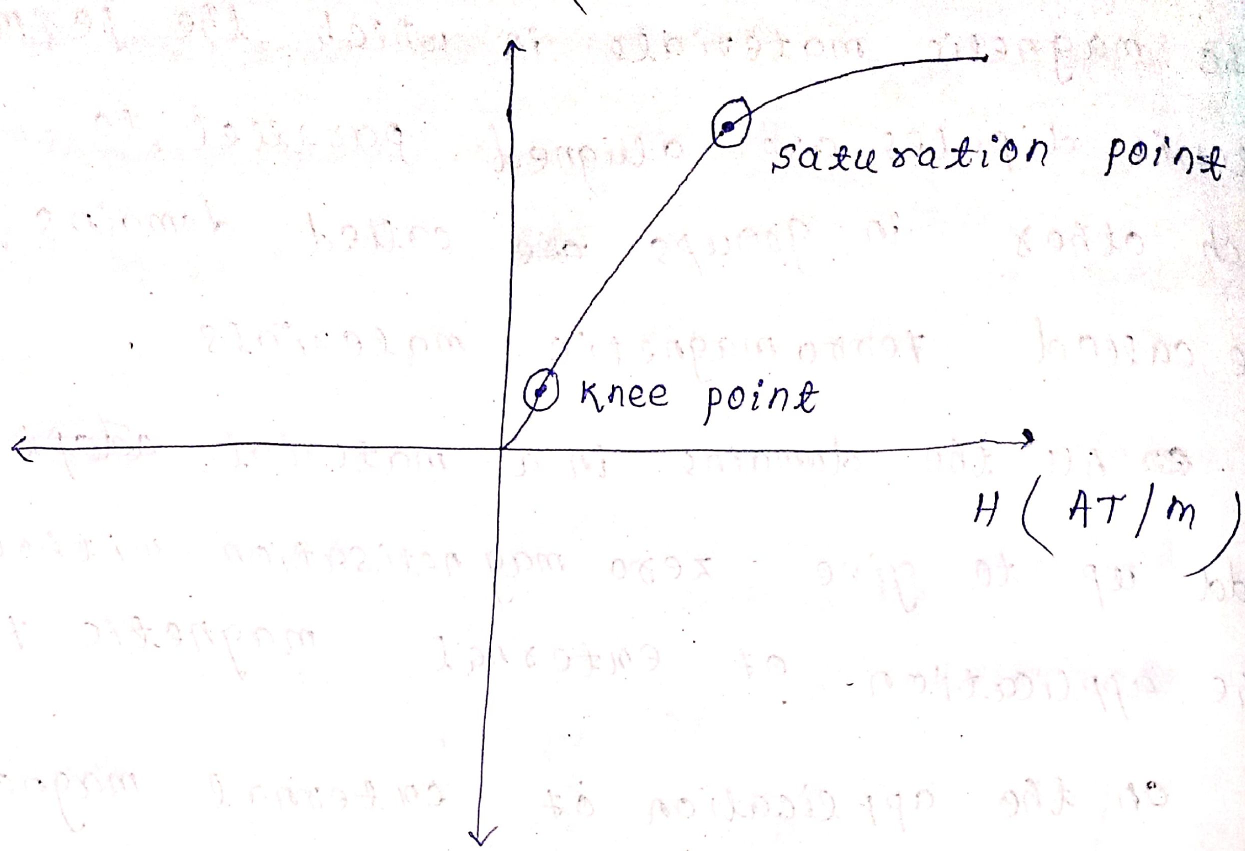
The magnetic materials in which the permanent atomic dipoles are alligned parallel to each other in groups ~~are~~ called domains are called ferromagnetic materials.

~~▪~~ All the domains in a material ~~adopt~~ add up to give zero magnetisation without the application of external magnetic field

On the application of external magnetic field, the domains orient themselves in that direction giving rise to strong positive magnetisation.

$\mu_r > 1$

B - H curve :-



→ The curve plotted between magnetic flux density (B) and magnetic field intensity (H) is called B-H curve or magnetisation curve.

→ when external magnetic field is increased the domains of the ferromagnetic material does not orient themselves parallel to the external field initially till the knee point

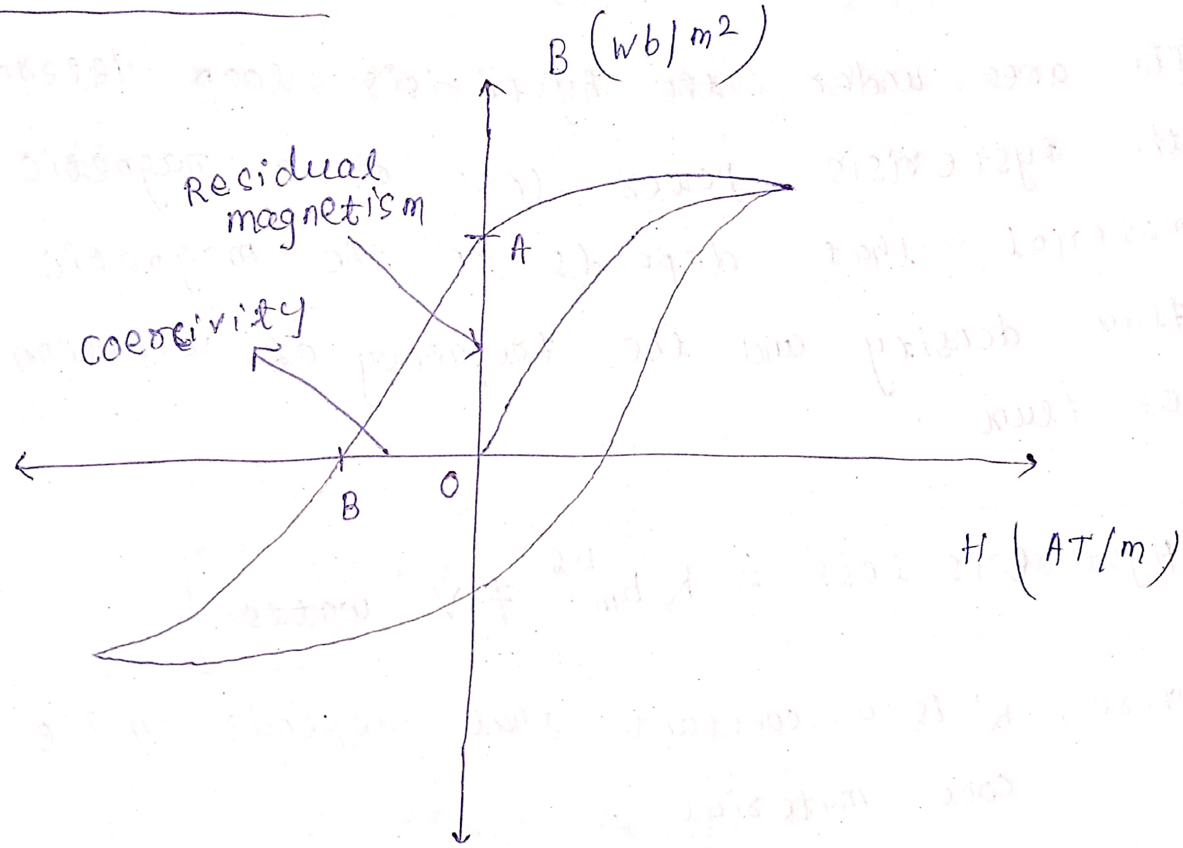
→ After that the magnetic domains gets alligned parallel to the external magnetic field and there is a linear increase of magnetic field with the magnetic flux density.

→ After all the domains are completely alligned with the external magnetic field, there is no rise in magnetic flux density with the increase in magnetic field intensity.

→ The slope of B-H curve gives the permeability of the ferromagnetic material.

$$\frac{B}{H} = \mu$$

Hysterisis loop :-



OA = Residual magnetism / Remnant magnetism / Retentivity

OB = coercivity

→ when a magnetic material is subjected to cyclical changes of magnetisation and demagnetisation, then it forms a loop called Hysterisis loop.

→ The property of magnetic flux density (B) lagging behind magnetic field intensity (H) is a characteristic of ferromagnetic material.

→ This property of lagging behind of 'B' from 'H' is called Hysterisis.

→ The area under the hysterisis loop determine the hysterisis power loss of a magnetic material that depends on the magnetic flux density and the frequency of variation of flux.

$$\text{Hysteresis loss} = K B_m^{1.6} f V \text{ watts}$$

where, 'K' is a constant that depends on the core material.

'B_m' is the maximum flux density of the material.

'f' is the frequency of variation of flux.

'V' is the volume of the core material in m^3.

$P_h \propto f$

Residual magnetism :-

The remaining magnetic flux density when magnetic field intensity 'H' is zero is called Retentivity or residual magnetism or Remnant magnetism. (OA portion is called residual magnetism)

coercivity :-

when the magnetising force is applied in reverse direction that causes magnetic flux density to become zero is called coercivity or the coercive force. (OB portion)

Note

B = +ve H = 0	Retentivity.
H = -ve B = 0	coercivity.

Eddy current Loss :-

→ Magnetic materials when placed in alternating magnetic fields undergo rate of change of flux linkage. Due to Faraday's law of Electromagnetic Induction (EMI), emf is induced in the magnetic material which leads to flow of current called the eddy current in the material.

→ This currents cause loss of energy called I^2R loss resulting in heating of the material.

The expression for eddy current loss is given by,

$$\text{Eddy current loss} = K\, B_m^2 f^2 t^2 V \text{ watts}$$

$$P_e \propto f^2$$

Q. At 50 Hz frequency a magnetic material has 400 watt hysteresis loss. Find the eddy current loss at 60 HZ.

sol^n

Curie point :- (Madam Curie)

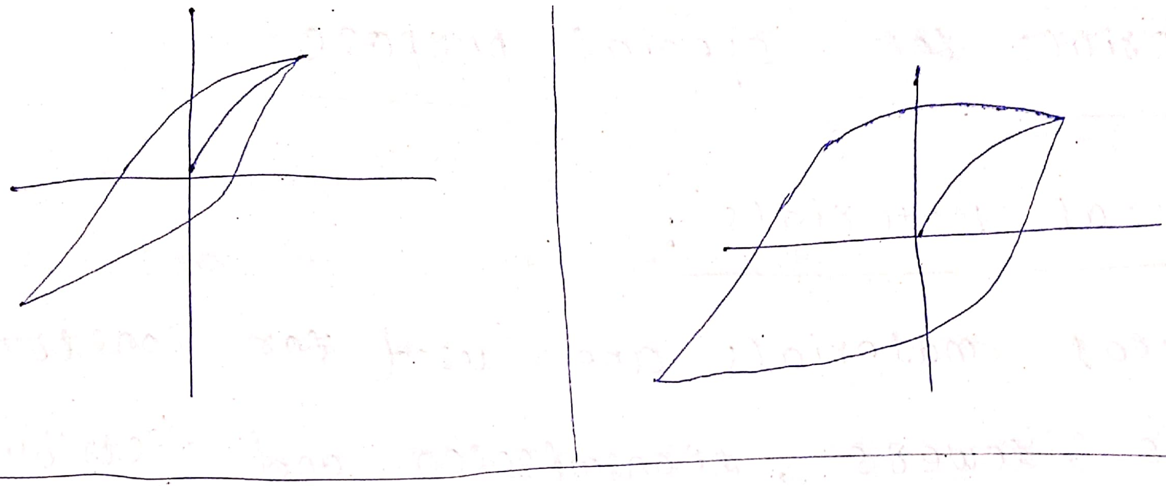
It is defined as the critical temperature above which ferromagnetic material lose their magnetic properties.

Magnetostriction :-

When magnetic materials are subjected to rapidly changing alternating magnetic fields, there is a rapid and continuous extension and contraction of the material giving rise to vibrations. This phenomenon is called magnetostriction.

This is the major cause of hum in transformers.

Soft magnetic material	Hard magnetic material
(1) Magnetic materials which have a steeply rising magnetisation curve and narrow hysteresis loop are called soft magnetic materials.	(1) Magnetic materials which have a gradually rising magnetisation curve and large hysteresis loop area are called hard magnetic materials.
(2) They have small energy loss during cyclic magnetisation.	(2) They have large energy loss during cyclic magnetisation.
(3) Used for building cores that are used in alternating magnetic fields like electric machines, transformers, electromagnets, reactors, relays.	(3) Used for making permanent magnets.
(4) Ex:- The most common soft magnetic materials are soft iron, Nickel-iron alloys and soft ferrites.	(4) The examples of hard magnetic material are carbon steel, tungsten steel, Alnico and hard ferrites.



Magnetic Anisotropy :-

Directional dependence of magnetic property :-

Materials for special purpose

Structural Materials :-

Structural materials are used for construction of poles, towers, transmission and distribution lines, frames of rotating machines, frames of electrical heaters etc.

The common structural materials used are cast iron, steel, timber and reinforced concrete.

(i) Cast iron is used as a material for frames of small and medium sized electrical machines.

(ii) Steel is used to make fabricated frames of large electrical machines, transformer tanks, fabrication of transmission towers.

(iii) Timber

Timber is used for making poles for overhead lines.

(iv) RCC

Reinforced concrete cement is used for making transmission towers and distribution poles for overhead transmission and distribution lines.

protective materials :-

→ protective materials are used to provide protection to electrical equipments in the form of lead sheathing, steel armouring of cables, bitumens in cable joint boxes and underground cables.

→ The common protectective materials are lead, steel (steel tapes, wires and strips), bitumens.

Lead

→ Lead is a soft, heavy and bluish gray metal, highly resistant to chemical actions. It forms alloys with tin and zinc.

→ It is used in storage batteries, sheathing of cables and in bearing metals.

Steel tapes, wires and strips :-

→ It is used as protective material for mining cables, underground cables, weather proof cables etc.

Bitumens :-

It is used for protection against corrosion.

Thermocouple materials :-

When two metals of different temperature co-efficient of resistance are joined together, an emf exists across the junction. This emf is directly proportional to the temperature of the junctions. The resultant emf is proportional to the temperature difference of the junction and is called thermoelectric emf.

The materials used for thermocouples are copper / constantan, Iron/constantan, platinum / platinum rhodium, Nickel / Nickel chromi

→ Thermocouples are used for measurement of temperature due to the temperature dependant emf,

Thermocouple pyrometer.

If one junction is held at constant temperat called the cold junction, then the emf produce becomes a measure of the temperature of the other junction.

Bimetals :-

A Bimetal is made up of two metallic strips of different alloys with different thermal co-efficient of expansion. At a certain temperature, the strip will bend and actuate a switch.

When heated the metal with greater co-efficient of expansion is on the outside of the arc and the metal with smaller co-efficient is on the inside.

Alloys of Iron and Nickel have lower co-efficient of thermal expansion and alloy of Brass, constantan have higher co-efficient of thermal Expansion.

Applications :-

Bimetallic strips are used in relays and regulators for overload protection of electrical machines and equipments.

Soldering materials :-

→ An alloy of two or more metals of low melting point used for creating joints is known as soldering.

→ The alloy used for joining the metals is called a solder.

→ The most common solder contains 50 % tin and 50 % lead.

Solders are of two types. soft solders and hard solders.

→ soft solders are made up of lead and tin in different proportion.

→ Hard solders are made up of other material having melting point above tin and lead solders.

Ex :- Silver solder, Aluminium solder, Copper - zinc solder.

Application :-

→ Hard solders are used in power apparatus for making permanent connection.

→ soft solder are used in electronic devices.

Fuse and Fuse material :-

Fuse is a protective device which consists of a thin strip of wire having low melting point under fault condition when temperature of the strip increases, it breaks the circuit interrupting the supply.

The fuse material should posses the following properties :

(1) Low resistivity :-

The fuse material should be having low resistivity and high conductivity to make the quenching of arc easier.

(2) Low conductivity :-

Fuse material should have low conductivity to extinguish an arc.

(3) Low melting point :-

Fuse material should have low melting point to detect a fault easily.

Fuse law states that, $I^2 \alpha d^3$ or $I \alpha d^{3/2}$

where, 'I' is the current flowing through the fuse wire.

'd' is the diameter of the cylindric wire.

Dehydrating material :-

→ Dehydrating material are the inorganic chemicals which have moisture absorbing property.

→ Silica gel is a colloidal inorganic substance which has dehumidifying and dehydrating property.

→ It acts as a catalyst carrier and is used in transformer tanks.

→ It removes moisture from air entering a transformer.

* Laminates, Adhesives, Enamels and varnish

Laminates :-

When multiple thin layers of insulating material like paper, cloth, mica, glass are bonded together by a suitable binder for specific insulation application is called a laminate. Laminates can be in the form of insulated boards, tubes, rods.

Application :-

paper reinforced laminates are used in transformers, printed circuits involving power frequencies and voltages upto 1 KV.

→ Asbestos reinforced laminates are used for high temperature installations with temperature withstanding capacity upto 190°C.

→ Glass and reinforced laminates belongs to H-type material and are used in printed circuit for High frequencies.

Adhesives :-

→ Adhesives or binders are a class of material composition required to carry out bonding between two or more solid surfaces.

→ Adhesives are used for making laminates having excellent thermal and insulating property.

Basic materials used as adhesives are

(1) Natural shellac :-

Resin, asphalt, Gum, starch are used as adhesives for wood, glass, paper etc.

(2) Thermoplastic :-

cellulosic, acrylic, vinyl, amides are used as adhesives for leather, paper, cloth, glass, Plastics, metals and wood.

(3) Thermosetting :-

Phenol, formaldehyde, melamine formaldehyde, urea formaldehyde, silicons are used as adhesives for wood, cloth, paper, Rubber, plastics and fabrics.

(4) Rubber :-

Natural, butyl, ~~cloo~~ chlorophoine are used as adhesives for paper, wood, plastics, metals and wood.

5) <u>inorganic</u> :-

portland cement, plaster of paris, glass, are used as adhesives for cellulose products and ceramics.

<u>Applications</u> :-

Adhesives are used for manufacturing of laminated structures like insulated boards, coil winding cylinder, rods, tubes and special type insulators.

<u>Enamels</u> :-

Enamel is a fusible, insulated coating of organic base material applied on the conducting surface.

The different types of enamels are

(1) <u>Oleo resin enamel</u> :-

Natural resin and drying oils are used for making oleoresin enamel.

(2) <u>poly amide resin enamel</u> :-

These are tough, resistant to solvents and easily solderable.

(3) <u>polyvinyl formal resin enamel</u> :-

These are tough and abrasion resistant.

(4) Acrylic resin enamel :-

These are resistance to industrial solvent and posses flexibility with good abrasion resistance.

(5) Poly tetra fluoro Ethylene resin enamel :-

These enamels exhibit highest temperature stability upto 200°C.

Application :-

Enamels are used for coating wires in windings of low rated motors, transformers and various instruments.

Varnish :-

Varnish is a liquid usually a solution of resinous matter in oil or a volatile liquid which when applied to the surface dries by evapouration resulting in hard, shining coating resistant to air and water.

From application point of view, varnish are classified into following types.

(1) coating varnish :-

Coating varnish increases the mechanical strength of an assembly and surface leakage resistivity protecting the substance from oxidation, corrosion, moisture absorbtion and solvent attack.

(2) Impregnating varnish :-

These varnish are utilized with porous and fibrous insulations like paper, card board, fabrics, glass which are used in capacitors, transformers, motor winding.

(3) Adhesive varnish :-

These are utilized as binders for mica, glass and other insulating materials.

(4) Lacquer :-

It is used for protecting wood and metal surface from external weather conditions. It is a solution of Nitrocellulose, ketone, alcohol, hydrocarbon, plasticizer and pigments.

Manufacturing of varnishes takes place with substances like oils, solvents, thinners, resins and driers.