

MaterialConducting Materials :->

The materials which conduct electricity is known as conducting materials.

Insulating material :-> The material which are used for preventing the flow of electricity is known as non-conducting or insulating material.

Resistivity :->

According to Ohm's law $V = IR$

Thus $R \propto l$

$R \propto \frac{l}{a}$ OR

$R \uparrow$ as $a \downarrow$ $R \uparrow$ as $l \uparrow$
inversely.

$$\Rightarrow R = \rho \frac{l}{a} \text{ ohm.}$$

Where " ρ " is the coefficient of proportionality and is called the resistivity or specific resistance of the material.

R :- Resistance of material

ρ :- Resistivity of the material in ohm-m

a :- area of cross section of material

l :- length of the material.

Factors affecting resistivity: →

The resistivity of material is not constant. The factors which affect the value of resistivity of a material are temperature, alloying, & mechanical straining.

Effect of temp. on resistivity: →

The resistance of most of the conducting materials increases with temperature. The change in resistance of a material per ohm / degree change in temperature is called temperature coefficient.

The resistance of the conductor changes with temperature according to the law:-

$$R_t = R_0 (1 + \alpha t) \text{ --- (i)}$$

Where R_t & R_0 are respectively the resistance of the conductor at t & 0°C & α is the temp. coefficient is the resistance of the same material at any other temp. If it be R_{t_1} then the eqⁿ become:-

$$R_{t_1} = R_0 (1 + \alpha t_1) \text{ --- (ii)}$$

$$\frac{R_{t1}}{R_t} = \frac{R_0 (1 + \alpha t_1)}{R_0 (1 + \alpha t)}$$

$$\Rightarrow \frac{R_{t1}}{R_t} = \frac{1 + \alpha t_1}{1 + \alpha t}$$

Adding and subtracting αt in numerator

$$\frac{R_{t1}}{R_t} = \frac{1 + \alpha t + \alpha t_1 - \alpha t}{1 + \alpha t}$$

$$= \frac{1 + \alpha t}{1 + \alpha t} + \frac{\alpha(t_1 - t)}{1 + \alpha t}$$

$$= 1 + \frac{\alpha(t_1 - t)}{1 + \alpha t}$$

$$\Rightarrow R_{t1} = R_t \left[1 + \frac{\alpha(t_1 - t)}{1 + \alpha t} \right]$$

This means that the resistance of any temp t_1 degrees can be calculated if the resistance at t ^{degree} is known.

Effect of alloying on resistivity: →

Alloying is another factor which effect the resistivity of a material by adding some impurities to a metal then its resistivity can be increased.

So, alloy have higher resistivity than the pure base metal. When a metal is alloyed it also requires properties like higher mechanical strength.

exp:- When copper is alloyed with zinc the alloyed metal is called Brass.

Copper (60%) + Zinc (40%) = Brass.

By alloying copper with zinc its resistivity is increased where conductivity is decreased. By four times but the tensile strength is much more than that of copper. & therefore may be used for making structural product such as rods, shafts, plug points, socket out-let, knits, switches etc.

Tensile strength → The resistance of a material to breaking under tension.

Effect of mechanical stressing on resistivity:

The resistivity of a material also changes under influence of mechanical treatment. The fabrication of conductor from the input to the final stage initially not working & finally cold drawing. This is also called as cold working operation. This tends to harden the material & increase its tensile strength & also increase its resistivity.

Mechanical stressing increases the resistivity & decreases the conductivity.

Classification of conducting material (1) low (2) high

(1) Low resistivity material are used in house wiring as conductor for transmission & distribution. In winding of transformer & machines like generator & motor. Low resistivity materials are used in all such applications where power loss & voltage drop should be low when power is transmitted wire having such value of resistivity that the voltage drop & the power loss in the wire as possible.

ex: $\rightarrow$ copper, aluminium.

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* silver has lower resistivity than copper but it is costly so we do not use it.

Properties of low resistivity: $\rightarrow$

(i) Low temperature coefficient: -

This means that the change in resistance with change in temperature should be low. The resistance of the transmission line will increase when exposed to hot summer sun. This will cause increase in voltage drop and power loss in the transmission line. If the conducting material of the winding has high temperature coefficient of resistance then the voltage drop & power losses will be high.

(ii) Sufficient mechanical strength: -

The conducting material used for the winding of transformer motors and generator developed mechanical forces when loaded which can become very large at a high current flows due to short circuit. The conducting material should possess high mechanical strength.

(iii) Ductility! - Ductility is the property of a material which allows it to be drawn out into a wire. Conductors are required in different sizes & shapes.

Solderability: → Conductors have often to be ~~joined~~ jointed. The joint should be such that minimum contact resistance results at the joint is soldered.

Resistance to corrosion! - The conducting material should be that it is not corroded when used in open atmosphere.

(2) High resistivity Material! -

High resistivity materials are used for making resistance element for heating devices, starters for electric motors, resistor used in measuring element, rheostat, & for filament in incandescent lamp.

If low resistivity materials were used for such application the length of the wire would be too large, which would increase the overall size of the equipment.

Properties :-(i) low temp. coefficient :-

High resistivity material are used as shunts in electrical measuring instruments. The material of the element should have negligible temperature coefficient of resistance otherwise the accuracy of measurement will be reduced.

(ii) High melting Point :- In application like loading rheostat & starters for electrical motors, the material of the resistance element should be able to withstand high temperature for a long time without melting.
eg :- Room heaters, furnaces.

(iii) No tendency for oxidation :- Material used as high resistance element in heating applications should be able to withstand high temperature for a long time without oxidation.

(iv) Ductility :- High resistance material are required in the shape of very thin wire gauge or wire wound resistor but in case of ovens, heaters, starters

Thin wires are used. High resistance material to be used for such application should therefore be capable of being drawn into wires of different sizes.

(V) High Mechanical Strength: → High resistivity material to be used for application where wire must be very thin are required to have high tensile strength other wise they may be broken down during the operation.

Low Resistivity Material & their application!

(i) Copper: → Amongst all the conducting materials copper is most widely used metal because it has high conductivity & low resistivity. ~~Silver has low resistivity than copper but because of its high cost it is not used as a conducting material. Copper is a non magnetic metal & has physical, chemical & electrical properties.~~

Copper is reddish in colour and can be available in hard form. Hard copper becomes soft after annealing. Process involves heating at a specific temperature & then cooling. After annealing copper is then

* Resistivity of ~~hard~~ annealed copper is $1.72 \times 10^{-8} \text{ ohm}$

* Resistivity of hard copper is $1.78 \times 10^{-8} \text{ ohm}$ at $20^\circ \text{ temperature}$.

* Density & melting point of hard copper is 8.93 & 1084°C respectively.

* Density & melting point of annealed copper are 8.89 & 1084°C respectively.

~~* Density & melting point of annealed copper are 8.89 & 1084°C respectively.~~

* The tensile strength of copper varies from 8.15 to 4.72 tonnes/cm²

copper can easily be soldered & welded which are necessary in electrical wiring. Annealed copper is used in insulated conductors in low voltage power cables, winding wires for electrical machines, transformers, flexible wire & in making coil for many purpose.

The availability of copper has become decreases in India. Copper in pure form is not much used as electrical contact material, when $10\% - 30\%$ of nickel is

Mixed with it then it becomes harder and cheaper. Due to its high electrical & thermal conductivity it is commonly used as a contact material for control relays, motor starter switches & tape changers. It has poor resistance to oxidation which lowers its efficiency.

(ii) SILVER: → Pure silver has high electrical conductivity & is harder to make it harder so 15% of copper is added into it. To make it more harder for use in commutator segment of small DC motor / generator as alloy of copper & silver containing 40% copper is used.

For process & collecting of DC motor silver-graphite alloy containing a small percent of graphite is used because it provides sliding lubrication.

(iii) GOLD: → Gold is the best known electrical conductor. It is found in all over the world but not in sufficient quantity to make it economical. Gold is generally found in rock & ores of other metals & it is also found in the form of dust in the belt of rivers.

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Answer: Silver is used as metal for comm.

Gold has density of 19.3 times rate of water 20°C . It melts at 1063°C & boils at 2700°C . It is largely used as alloy to make coins & Jewellery.

(iv) Aluminium: $\rightarrow$ Aluminium is widely available and used extensively in the field of electrical energy. Its resistivity is $2.8 \times 10^{-8} \text{ ohm m}$, i.e. about 1.6 times higher than copper.

* Density of aluminium is 2.68 which means that aluminium is much lighter than copper.

* Melting point of aluminium is 655°C .

Aluminium is a soft metal but when alloyed with some other material like magnesium, silicon or iron. It ~~acquires~~ acquires high mechanical strength & can be used for overhead transmission line.

(v) 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 acquires very good mechanical properties, with the addition of small percentage of carbon increases but at the same its

ductility decreases.

Steel can be classified as 3 types :-

- (i) ~~low~~ mild steel $\rightarrow$ 0.25 % carbon.
- (ii) medium steel = 0.45 % carbon
- (iii) High carbon steel = 0.70 % carbon.

The resistivity of steel is 8 to 9 times higher than copper due to this reason steel is not generally used as a conducting material. Although it has higher mechanical properties & easily available.

Stranded conductors :-

When a single conductor of large cross-section is used it becomes rigid in construction & breakdown while handling to avoid this conductors are made of no. of thin wire (strands) together called as strands. Stranding makes the conductor flexible and eliminates its breakdown.

A stranded conductor consists of six wires around one wire. Then the 12 wires around previous six. Then 18 wires around 12. Then 24 wires around 18 & so on. The number of layers to be provided will depend upon the no. of wires to be provided.

Bundle conductor:->

The adoption of bundle conductor ~~is~~ high in extra high power transmission enables ~~stand~~ stranded conductor to employed & gives an increased current carrying capacity compare with a single conductor of equivalent cross-sectional area

Low Resistivity Copper alloy:->

Brass:-> When copper is alloyed with zinc it is called as brass. brass has high tensile strength but lower conductivity than copper. it can be easily shaped by pressing it is weldable & solderable.

Uses:-> Plug points, socket outlets, switches, tube holders.

Bronze:-> Copper when alloyed with tin (8% to 16%) & a very small percentage of third element like gallium, bismuth, phosphorus, silicon is called a bronze. Bronzes are given their name based on the ~~third~~ third element which is added to copper & tin to form the alloyed

eg:-> Silicon bronze, bronze all bronze are possess high mechanical strength & are

compare to copper but have lower conductivity.

~~Be alloy~~ Beryllium copper alloyed →

The copper alloyed containing Beryllium is called as Bronze. It is high conductivity & high mechanical strength its hardening & elasticity property can be change by appropriate heat treatment.

It is used for making permanent carrying spring.

High resistivity Material & their application

(i) Tungsten → It is a very hard metal. Resistivity of tungsten is about twice that of aluminium. Its melting point is the highest of all metal. That is 3300°C it can be drawn into very thin wire required for making filament. The thinner the tungsten wire the greater is its tensile strength. Tungsten is used in lamps, as heater in electronic tube.

(ii) Carbon → Carbon material used in the field of electrical engineering & other parts of carbon like coal. The manufacturing process of electrical carbon consists of grinding of raw materials, then mixing the powdered carbon

With a binding agent coal tar to increase or conductivity of carbon. Products of different kinds of additive like copper or bronze are mixed with the carbon.

Use
characteristics of Carbon: →

Carbon is used in the application. Like brushes for electrical machine & apparatus, electrical non wire resistor & some other tele-communication equipment battery cell, element etc. arc.

Characteristics of Carbon: →

(i) It has a very high value of resistivity.

(ii) Negative temperature coefficient of resistance.

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(iii) Pressure sensitive

(ii) Platinum: → Platinum is greyish white metal. It is ductile. Platinum is a heavy metal having specific weight 21.4 gm/cm^3 .

i) The resistivity of Platinum is $0.1 \times 10^{-6} \Omega \text{m.m}$

ii) Its melting point is 1775°C .

iii) Its temperature coefficient is $0.0030^\circ/\text{C}$.
Platinum can be drawn into thin wires & strips.

(iv) Mercury $\rightarrow$ Mercury is a heavy silvery white metal. Its specific weight is 13.55 gm/cm^3 . Its boiling point is 357°C . ~~Its resistivity is~~

i) Its resistivity & temp coefficient of resistance are respectively $0.95 \times 10^{-6} \Omega \text{m.m}$ & 0.00027°C .

Mercury is very poisonous. It is used in the thermometer, gas filled tubes, electrical switches.

Super conducting material:-

Many metal & compounds have super conductivity property at low temperature.

Application of Superconductor material:-

Electrical Machine:- Efforts are being made at present to develop electrical

Machine & transformer utilizing super conductivity.

Power Cables :- Super conducting material is used for power cable with enable transmission of power over very long distance using a diameter of a few centimeters without any significant power loss or voltage drop.

Electro Magnet :- Super conducting solid/liquid which do not produce any heat during operation have been produced if there been possible to design electro magnet using super conductivity for use in laboratory & for low temperature devices like the Magnet.

Future Prospects :-

It must be realised that the application required the conductor to be maintain at temperature very close to 0°K. Presently helium is used to achieve low temperature required for super conductivity. Because helium being an expensive gas efforts are being made to develop compounds which exhibits super conductivity at temperature

to be obtain by the easily available.

Superconductivity : →

It has been stated earlier that the resistivity of most metals increases with increase in temperature. and vice versa. There are some metal & chemical compounds whose resistivity becomes zero when their temperature brought near 0°Kelvin (-273°C). At this stage such metal or compounds are said to have obtained superconductivity.

There are two types of superconductor commonly known as type-I & type-II superconductor. Type-I superconductor are soft superconductor whereas as type-II superconductor are hard superconductors.

(Semiconducting Material)

Semiconductor:-

As the name indicates, a semiconductor is neither a good conductor nor a good insulator. Typical semiconductor materials are Germanium & Silicon each of which have four valance electrons.

Electron Energy & Energy Band Theory:-

→ 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 level of the electron.

→ This value is measured in electron volt (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 1 volt.

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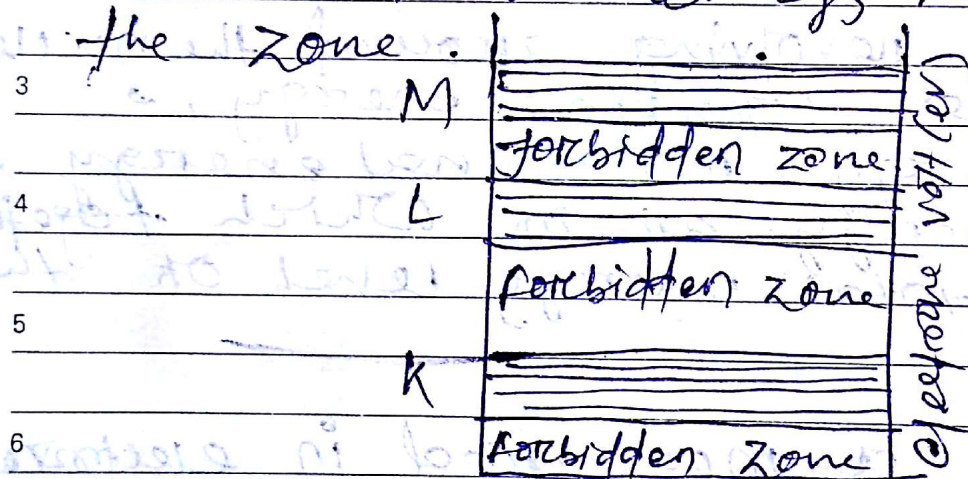
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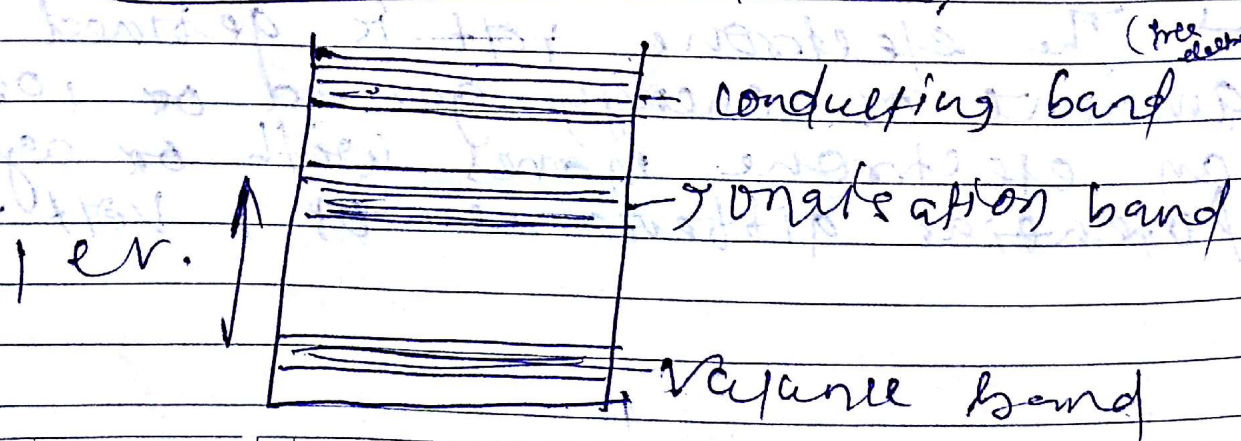
→ The larger the orbit in which an electron revolves the greater is its energy. Electrons with least energy closer to the nucleus each level containing electrons with higher energies.

→ The energy levels have been grouped into energy bands. The 'G' bands the area between them are called as forbidden zone. Because no electron can have an energy represented by the zone.



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Excitation of Atoms:



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Energy band representation of Ionisation: →

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, required some additional energy. The additional energy can be obtained from source like light, heat, electrostatic, magnetic kinetic energy.

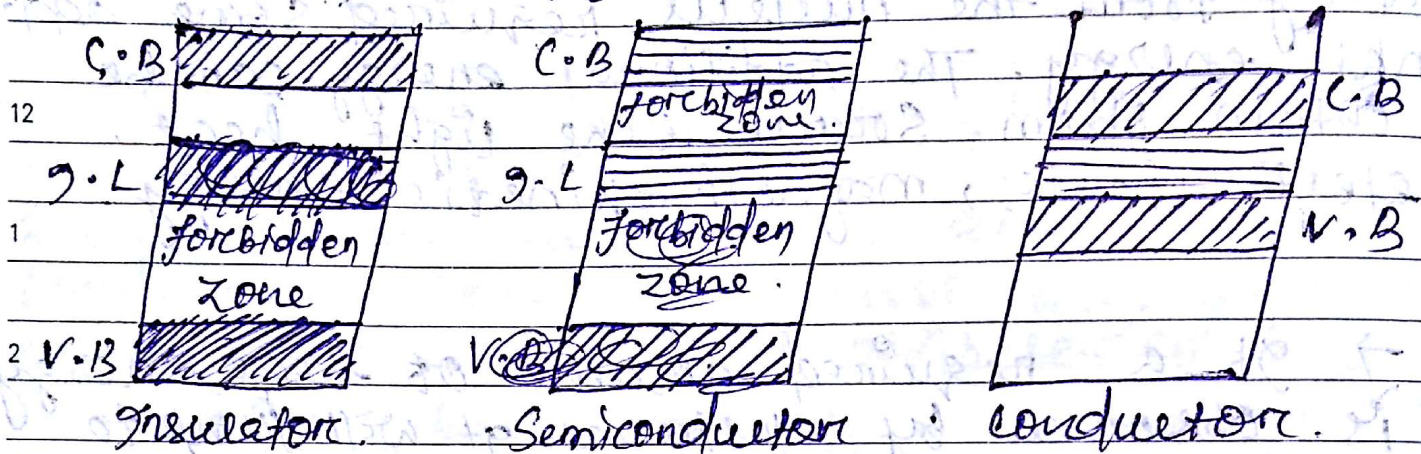
→ If a required amount of heat energy is observed by electron it will jump to higher energy level. So the atom is said to be an excited state.

→ When the required amount of light or heat energy is observed by valance electron. It will leave the valance band and may move up to ionisation level. If it does it is released from the attractive forces of nucleus. Then it is free to float around between the atoms & to conduct an electron above the conduction band & is called as free electron.

→ The word ionisation level is used because when an electron leaves the valance band the remaining atom is no longer neutral.

but have a positive charge and is called a positive ion the atom is said to be ionised.

Insulator, Semiconductor, & Conductor:-



→ The forbidden zone between the valance band & the conduction band is quite large in case of insulator this indicates that electrons in valance band required large amount of energy to move up and become free long as the valance electrons are unable to move upto the conduction band there can be electron flow.

→ In case of Semiconductor the forbidden zone is reduced so the valance electrons required less energy to free themselves from the attraction of the nucleus.

9 In case of conductor there is no gap between
 10 the valance band and the conduction band
 11 in some better conductors the conduction
 12 & valance band may overlap.

11 Semiconductor material:-

12 The electrical characteristics of semiconductor
 1 material form between insulator & conductor.

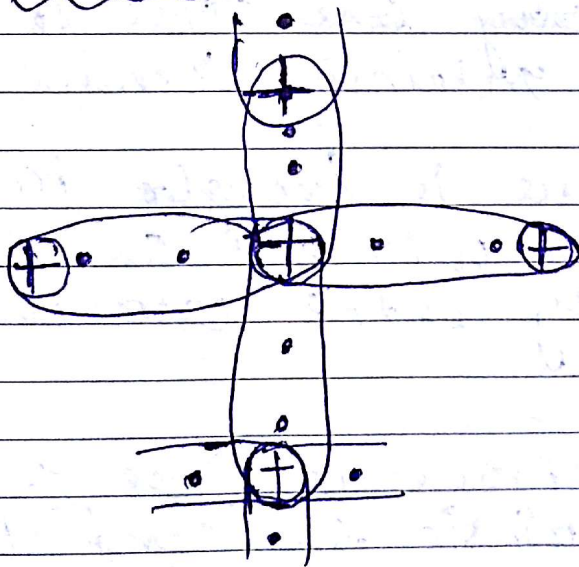
~~Semiconductor~~ $\rightarrow v.e \rightarrow 8$

2 insulator $\rightarrow v.e \rightarrow 8$

Semiconductor $\rightarrow v.e \rightarrow 4$

3 conductor $\rightarrow v.e \rightarrow 1$

4 Covalent Bond $\rightarrow$



→ A covalent bond results when each atom in order to fill its valanceing with 8 electrons, shares electron is called as covalent bond. Each bond with two electrons is an electron pair bond.

→ When atoms enter into covalent bonding each atom in effect has 8 valance electrons which would result in making such a material a good insulator.

Intrinsic Semiconductor: → (undoped or i-type)

→ If a crystal eg:- Silicon or germanium does not contain any impurity atoms i.e. it contains only one type of atoms it is called as intrinsic semiconductor.

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

→ When an electron is free from an atom of an intrinsic semiconductor material it breaks a covalent bond & leaves behind a valancey that is called as hole.

→ The free electrons & the hole form an electron-hole pair. The higher the temperature the greater the number of free electrons.

Extrinsic semiconductor : →

→ Pure form of material called as a extrinsic semiconductor.

→ Intrinsic semiconductor is little use as a semiconductor as a heat or light sensitive resistance.

→ We must add certain impurities to the semiconductor the addition of impurities is called as doping.

→ The material which has been doped is called as an extrinsic material. It is of two types :-

- (i) N-type
- (ii) P-type.

N-type semiconductor : →

→ 1 category of impurities has 5 valance electrons & is called the pentavalent group.

eg! → Germanium, Arsenic, Antimony, Phosphorus.

Majority & minority carrier: →

→ In N-type Material conduction takes place through the free electrons. These free electrons are called majority carriers.

→ The holes being small in ^{number} so it is called as minority carriers.

Semiconductor Material: →

There are 11 Semiconductor materials in the periodic table:-

Boron, Carbon, Silicon, Germanium, Arsenic, Phosphorus, Antimony, Sulphur, Selenium, Tellurium, & Iodine.

→ The resistance of semiconductor material can be controlled by the changes in temp. or by adding some impurities.

→ The resistance of the semiconductor can be controlled by some following factors:

1 → Illumination

2 → Voltage

3 → Electric field

→ Semiconductor can be classified as : →

(i) Monocrystal with an atomic lattice structure like carbon, silicon, germanium, a poly crystal with molecular lattice structure like ~~set~~ Seleniun, Tellurium, Antimony, Arsenic Phosphorus.

(ii) Oxide of such metal as copper, zinc, cadmium, titanium, tungsten, molybdenum.

(iii) Sulphides, copper, cadmium, ~~zinc~~ & other element.

(iv) chemical compound of certain element of the 3rd group of the periodic table like aluminium, gallium, indium.

Application of Semiconductor Material: →

→ It is used as rectifier (convert ac to dc)

→ Rectifier ! - Rectifier:

Germanium rectifier

Silicon rectifier.

→ A p-type & n-type material are joint together to form a junction called the Pn Junction.

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→ When an external voltage applied across two material a flow of current takes place. If the positive & negative terminal of the voltage source are connected respectively to the extreme ends to the P & N material voltage applied in this way is called forward biasing of P-N Junction.

→ If the applied voltage is reverse the positive of the supply connected to the N side & negative to P side there is no flow of current this is called reverse biasing.

→ So the Pn Junction offers high conductivity when forward biased & no conductivity when reverse biased. So the semiconductor can be used as rectifier.

→ Modern Pn Junction rectifiers use germanium or silicon as semiconductor material.

→ Germanium rectifier where ~~more~~ ^{invented} earlier than silicon rectifier.

→ Germanium has melting point of 938°C & silicon 1415°C .

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Germanium & Silicon semiconductor find wide use in high frequency. Germanium & silicon rectifier can operate at high current densities & reverse voltage with efficiency about 98%. Silicon rectifier can be operated by 20°C .

Copper Oxide & Cerium Rectifier →

Copper oxide rectifier is a Plate of 99.98% pure copper on which a film of cuprous oxide is produced by one side of the plate is cleaned of cuprous oxide and an electrode is soldered directly to the copper. The second electrode is soldered to the cuprous oxide film. When positive potential is applied to the oxide layer & negative to the copper is correspondence to forward biased in Pn junction.

Thermistor or temp. sensitive resistor →

Increasing the temperature of semiconductor material causes their resistance to decrease. This property has found application in devices called thermistor. Thermistor are thermally sensitive resistor. They are made from oxides of certain metal such as copper, manganese, cobalt, iron zinc.

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Thermistor find application in temperature measurement & controlled. Other application of thermistor include measurement of radio frequency, power, voltage regulation & timing & delay circuit.

Photoconductive Cell $\rightarrow$

The resistance of the semiconductor material is low under light & increases in darkness. This phenomena is used in a photoconductive cell. Where this phenomenon used in resistance cell a semiconductor material is connected in series with voltage source. The resistance of the semiconductor varies the intensity of light the current in the circuit is controlled.

eg: $\rightarrow$ Alarms, Smoke detector, & control for street light.

Photovoltaic cells $\rightarrow$

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Photovoltaic cells are device that develop an emf when illuminated so they convert light energy into electrical energy.

Varistors

Varistors — The resistance of the semiconductor varies with the applied voltage this property is used in device called varistor.

eg: $\rightarrow$ voltage stabilizer, motor speed controller.

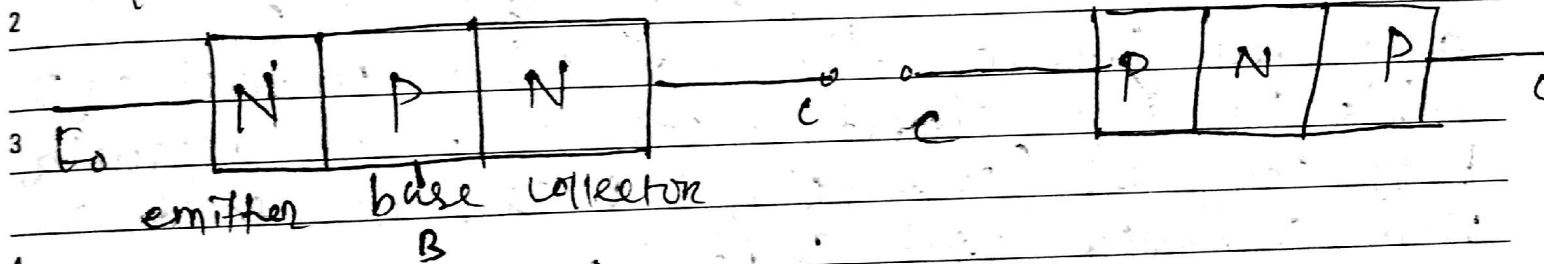
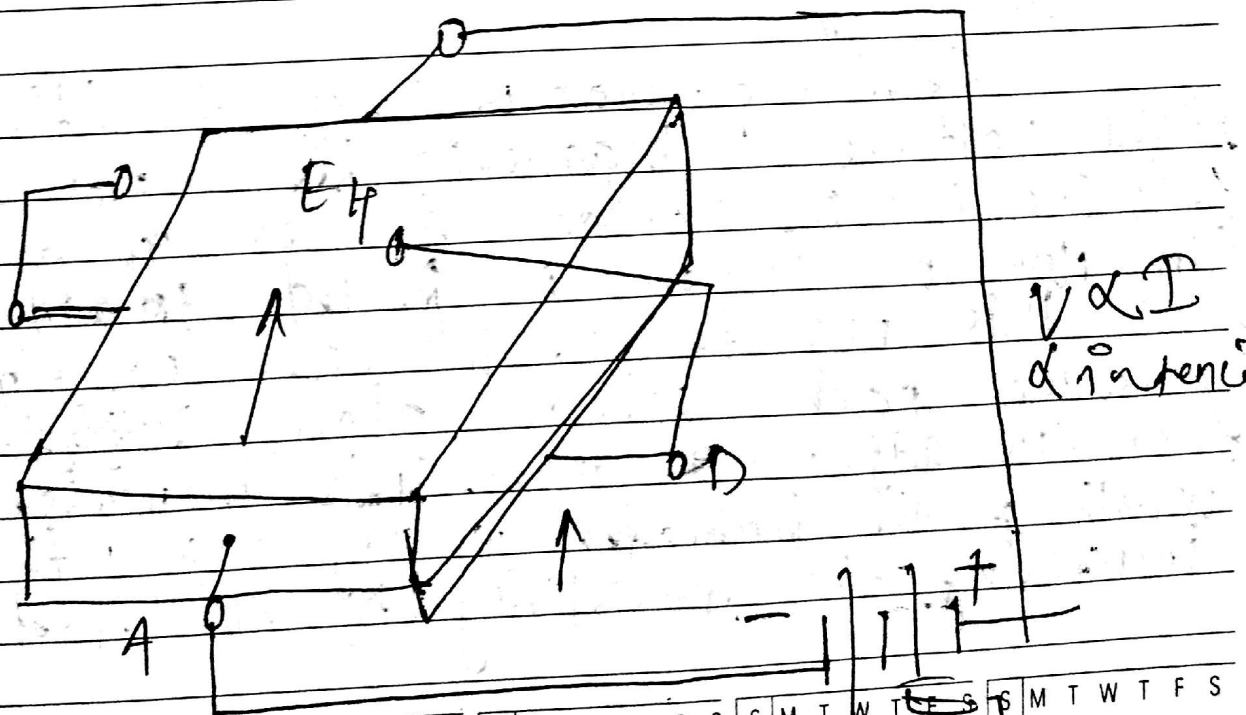
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Transistor $\rightarrow$

The resistance of semiconductor depends to a large extent on the magnitude of the electric field. The current in a semiconductor does not follow Ohm's law on increase the voltage. This property is used in the device called transistor. It has two junction 3 terminal device the two junction being formed by joining P-N-P material on N-P-N material.

Hall Effect generator $\rightarrow$ 

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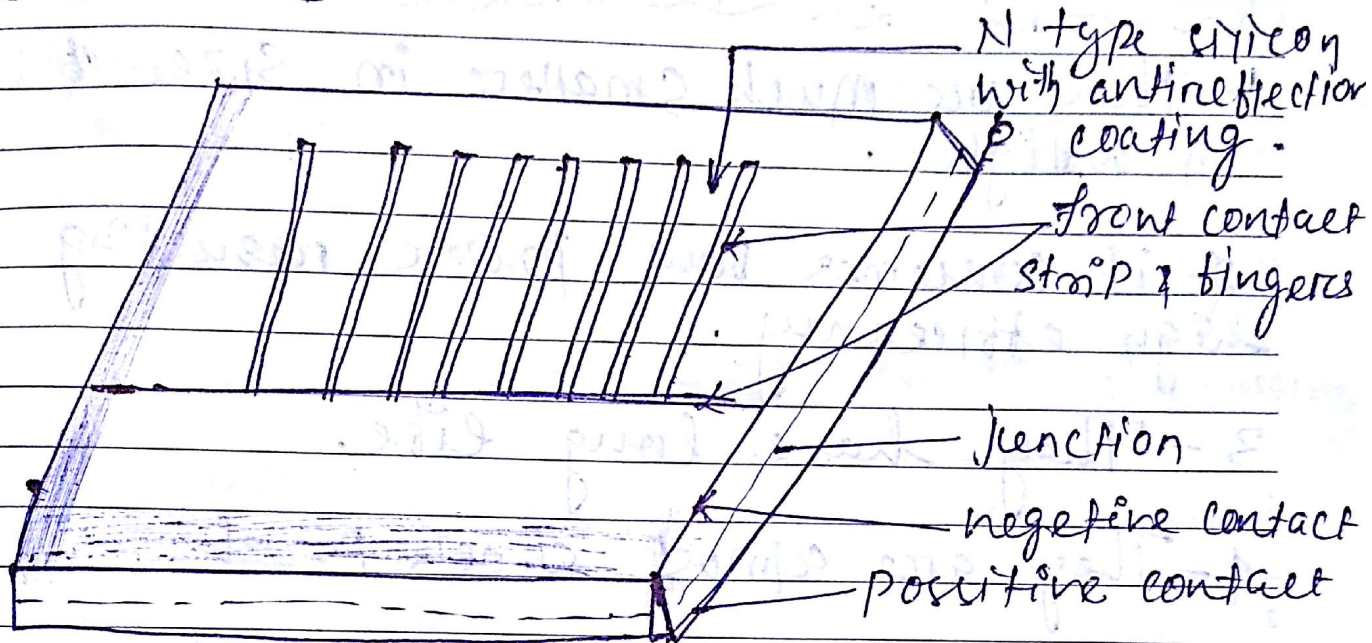
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When a current flows through a semiconductor bar placed in a magnetic field a voltage is developed at right angle to the both the magnetic field & the current. This voltage is proportional to the current & the intensity of the magnetic field. This is called as Hall effect.

Consider a semiconductor bar which has contact on four sides. If a voltage V is applied across the two opposite contacts A & B the current will flow. If a bar is placed perpendicular to the magnetic field 'B' & electric potential E_H is generated between the two other contacts C & D. This E_H is a direct measure of the magnetic field strength (intensity) & can be detected with a simple volt meter.

Strain Gauge →

Semiconductor is very sensitive to heat, light, voltage & magnetic field are also sensitive to mechanical forces. If a long thin rod of silicon is pulled from end to end this resistance increases continuously. Because each silicon atom slightly away from its adjacent atom. This increases the width of the forbidden energy gap, thus increasing the resistivity of the rod.

Solar Power : →

Sun is a vast source of energy. One of its important application is the conversion of solar power into electrical power. This phenomenon is called the Photo voltaic effect. Solar cell is the most important photovoltaic device which directly convert the solar radiation into electrical energy. Solar cell is basically a thin disc of PN junction with a large surface area.

A solar cell as shown in fig is developed in the form of slice of single crystal silicon. The typical size is $20\text{ mm} \times 20\text{ mm} \times 3\text{ mm}$. The ~~output configuration is obtained by~~ output depends upon the intensity of sunlight. As the cell is turned away from the sun the o/p decrease approximately as the cosine of angle of incidence.

Insulating Material

Any material that is able to insulate or to prevent the flow of electricity through it when a difference of potential is applied through it.

General Properties of Insulating Material:-

There are 4 different properties of insulating material:-

- 1) Visual Properties
- 2) Electrical Properties
- 3) Mechanical Properties
- 4) Chemical Properties
- 5) Thermal Properties

Electrical Properties:-

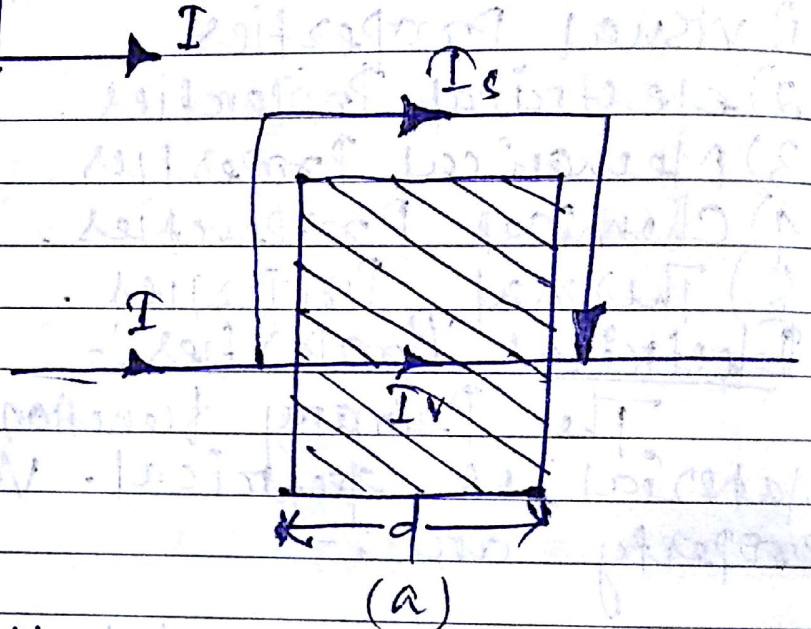
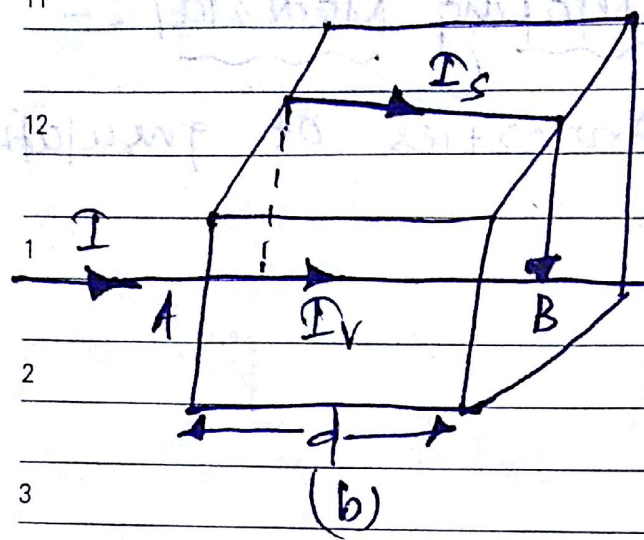
The primary function of an insulating material is electrical. Various electrical properties are:-

- i) Insulation Resistance $= R = V/I$
- ii) dielectrical strength
- iii) dielectric ~~loss~~ loss
- iv) dielectric constant

(i) Insulation Resistance:- This is the property by virtue of which a material resists the flow of electric current. It should be as high as possible.

An insulator to which a voltage 'V' is applied

Will have a small current i flowing through it. The insulation resistance R is given by $R = V/I$. There are i) volume resistance ii) surface resistance.



6 If a potential difference is applied across 'A' & 'B' the current will flow. The current is straight through the material & around the material over the surface the current that flows through the material is denoted by I_v & the current that flows over the surface is denoted by I_s .

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(i) Volume Resistance:-

The resistance offered to current I which flows through the material is called volume resistance for a cube of unit dimension is called as volume resistivity the volume resistivity expressed as:-

$$R_v = \frac{\rho_v d}{a}$$

Where R_v = Volume resistance

ρ_v = volume resistivity ohm.m

d = length of the current that passes through the material unit meter.

a = area of crosssection in sq.m.

(ii) Surface Resistance:- The resistance

offered to current I_s which flow over the surface is called surface resistance it depends upon the humidity.

(iii) Die-electric strength:- Every electrical apparatus is ^{design} ~~designed~~ & there should be operate within a define range of voltage & the operating voltage is increased gradually

3. Difference betⁿ material & Dielectric strength:

S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S

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Factor affecting die-electric Strength:-

i) Die-electric Strength decreases with rise in temperature in case of air in case of liquid insulator the effect varies with the type of oil or viscosity.

ii) Humidity generally decrease with the value of dielectric strength.

Die-electric constant:-

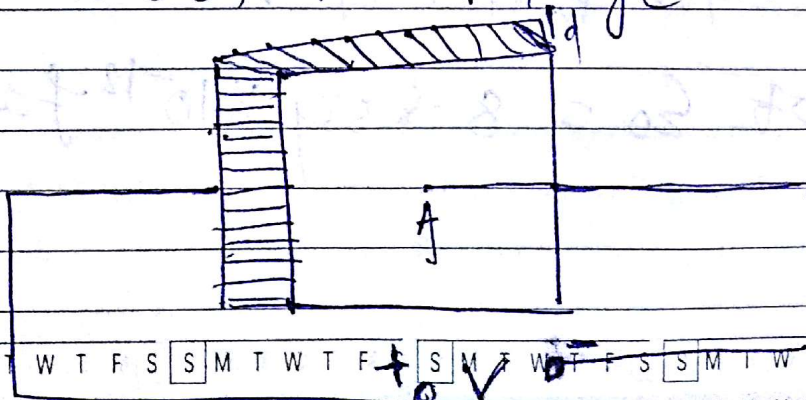
$C = \text{Capacity, capacitance.}$

Every insulating material has got basic property of storing charge (Q) when a voltage ' V ' is applied across it. If this charge is proportional to the voltage applied

$$Q \propto V$$

$$\Rightarrow Q = CV$$

$C = \text{Capacity or capacitance of the material across which the voltage is applied.}$



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Capacitance is different for different insulating material. The insulating material that causes the different of the value of capacitance physical dimension remain same is called the dielectric constant or permittivity.

The capacitance can expressed by :-

$$C \propto A/d$$

$$\Rightarrow C = \epsilon A/d$$

Where A = face area of insulation

d = distance between the insulation

ϵ = dielectric constant or permittivity.

$$\text{Also, } \boxed{\epsilon = \epsilon_0 \epsilon_r}$$

Where ϵ_0 = dielectric constant of the vacuum.

ϵ_r = dielectric constant of the material.

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

MaterialDielectric Constant (ϵ_r)

i) Paper

i) 2.0

2) Mica

ii) 2.5 - 6.6

3) Glass

iii) 5.4 - 9.9

4) Marble

iv) 8.3

5) diamond

v) 16.5

6) Oil

6) 2.2 - 4.7

7) Paraffin

7) 2.1 - 2.5

8) Porcelain

8) 5.7 - 6.8

9) Rubber

9) 2.0 - 3.5

10) Wood

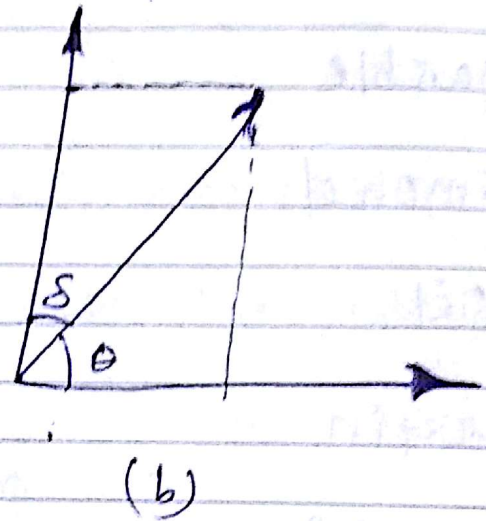
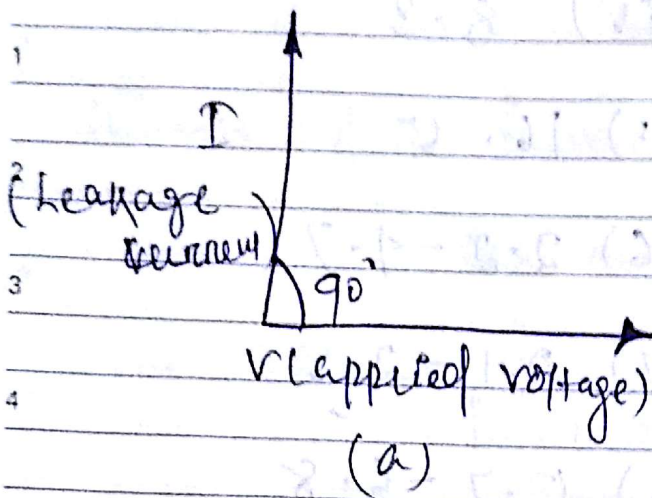
10) 2.5 - 7.7

11) Water

11) ~~2.0~~ 70

Dielectric Loss :-

When a Perfect insulation is subjected to alternating voltage it is like applying alternating voltage to a perfect capacitor. In such case there is no consumption of power. Only vacuum and Purified gases approach this perfection.



Phase Relation betⁿ leakage current & applied voltage in Dielectrics.

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In such cases the charging current would lead the applied voltage by 90° exactly. This would mean that there is no power loss in the insulation. In most insulating material that is not the case. There is a definite amount of dissipation of energy when an insulator is subjected to alternating voltage. It is this dissipation of energy that is called dielectric loss.

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Factors Affecting Dielectric Loss :-

- i) The loss increases proportionately with the frequency of applied voltage.
- ii) Presence of humidity increases the loss.
- iii) Temperature rise normally increases the loss.
- iv) Voltage increase causes increased dielectric loss.

Visual Properties :-

The following are the Visual Properties of Insulating Material. -

- a) Appearance.
- b) colour
- c) Crystallinity

These properties are not of any significant importance from engineering & therefore from performance point of view. However factor like appearance, bright colour & smooth to mat surface count to some extent towards the customer's selection of the insulating material.

Mechanical Properties →

The Property affecting the selection of Insulator ~~and~~ are many but we shall consider only those which are the comparatively great importance.

a) Mechanical Strength →

Most solid insulator have to withstand various load during manufacture as well as during operation when used on equipment. ~~for~~ Strength requirement for example strings of suspended porcelain insulator have to bear a great amount of load, plugs and sockets for domestic application have to withstand repeated operation.

The mechanical strength of insulator material depends upon a number of factor given below:-

i) Temperature rise → Temperature rise as a result of heat generation in the conductor & the dielectric loss in the insulator.

ii) Climatic effects → Humidity can also adversely affect mechanical strength of insulating material. Therefore, non hygroscopic material

0
10. Viscosity: → Viscosity in liquid dielectrics will affect manufacturing processes. For example,
11 in paper insulated cable the temperature at which the oil will penetrate through paper
12 will depend on its viscosity. The method to be used to purify the insulating oil used
1 in transformers & other application will depend upon the viscosity of the oil.

2
3. Porosity: → High Porosity insulating material
3 will increase the moisture holding capacity & consequently adversely affect electrical
4 properties. Therefore normally it is not desired to have a dielectric of high porosity.

5
6. Solubility: → In certain application can be applied only after it is dissolved in some solvent. In such cases the insulating material should be soluble in certain appropriate solvents.

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Thermal Properties: →

It is already mentioned that one of the major functions of insulation is heat transfer.

This example signifies that in an apparatus heat transfer function decides:-

(i) The voltage rating and up to what safe limit the voltage can be raised and for how much period without breakdown.

(ii) Loading A overloading current limitation.

(iii) Ambient temperature a maximum temp. of insulation can ~~with~~ withstand. discussed

Various Thermal Properties are given below:-
Melting point, flash point, volatility: →

→ Melting point assumes importance in specific cases like non-draining compound impregnated paper insulated cable etc.

→ flash point will ~~be~~ impose restriction in manufacturing processes to avoid possible ~~hazards~~ 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. A volatile material can not be good insulation.

Thermal conductivity :- Heat generated due to I^2R losses & dielectric losses will be dissipated through the insulation itself. How effectively this flow of heat takes place, depends on the thermal conductivity of the insulation.

Thermal Expansion :- An insulation with a high coefficient expansion poses problems. Repeated load cycles of an apparatus cause corresponding expansion & contraction of the insulation leading to the possibility of the formation of voids in it.

Heat Resistance :- This is general property which desires that a dielectric should withstand temperature variation within desirable limits without damaging its other important properties.

Chemical Properties :-

Chemical Resistance :-

Presence of gases, water, acids, alkalis & salts affects different insulation differently. Chemically a material is a better insulation if it resists chemical action.

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Certain plastic are found approaching this condition.

10 classification of granulation material on the basis thermal stability in service:-

Class

Maximum working temperature

Material on combination or nature

Y (formerly 0)

90°C

Cotton, silk, paper, Press, Press board, wood, PVC with on. With out plastic, vulcanized natural rubber.

1

105°C

Cotton, silk & paper When compressed or immersed in a liquid dielectric such as oil.

E

120°C

Material possessing a degree of thermal stability allowing them to be operated at temp 15°C higher than class. A material

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9	B	130°C	Mica, glass fibre, asbestos etc.
10	F	155°C	Mica, glass fibre, asbestos as well as other materials not necessarily inorganic, which by experience or accepted test can be shown to be capable operation at 155°C.
11			
12			
1	G		
2	H	180°C	Material such Silicon elastomer & combination of material such mica, glass fibre etc.
3			
4	C	above 180°C	mica, porcelain, glass & quartz with out an inorganic binder

Hygroscopicity: → Many generators come in contact with atmosphere either during manufacture or operation or both. The contact or generation with atmosphere is often so complete that even the less chemically aggressive atmosphere

Moisture due to high humidity atmosphere can affect ~~operation~~ generators in two ways: -

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(i) It acts on the surface of insulation.

(ii) It may be absorbed by the insulation.

However there are insulating material like paraffins, polythene, polystyrene, fluorothylene (PTFE) which are non-hygroscopic.

Ageing: → Ageing is the long time effect of

(1) i) Heat

ii) Chemical action.

(2) iii) Voltage application.

(3) These factors decides the natural life of an insulation & thus of an apparatus.

Insulating Material - Classification, properties applications: →

Insulating material on the basis of their physical & chemical ~~properties~~ structure may be classified in various categories as follows:-

(i) Fibrous materials

ii) Impregnated fibrous material.

iii) Non-resinous materials.

iv) Insulating liquids

v) Ceramics.

vi) Mica & mica products.

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- VII) Asbestos & asbestos products.
- VIII) Glass.
- IX) Natural & synthetic rubbers.
- X) Insulating resins & their products.
- XI) Laminates, Adhesives, Enamels & Varnishes.

12 Fibrous Materials: →

Fibrous material are either derived from animal origin or from cellulose which is the major solid constituent of vegetable plants. In certain other material like paper, wood, card board, the fibers is of the order of 25 mm length & 0.015 mm thickness.

a) wood! - wood was in the past frequently used for low voltage installation. This is light in weight with relative density varying between 0.5 & 1.0. Density strength varies, depending on the kind of wood & is betⁿ 700 & 1300 kg/cm² along the grain.

Paper and card board! - The base material for manufacturing insulating paper is coriferous wood. ~~The organic~~

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Crushed wood is boiled after adding some alkaline reagents. The process is called Sulphate process.

(C) insulating Textiles :->

Textiles are woven from fibrous material like cotton, jute and hemp. Sometimes silk from animal origin is used for special purpose. This class of material are mechanically strong in tensile and tear strength.

(d) Cotton :-> It is made in the form of fibre or cloth and tapes for the purpose of promoting insulation. It is a porous material and absorb water quickly. It get moist by moisture or humid air when it is damp, it is not a good insulator. It is used where flexibility is prime requirement & high humidity & humid atmosphere not envisaged.

(e) Silk :-> It is protein fibre consisting of long chain structure similar to that of cellulose. The silk yarn clothes are thin & strong. It has better factor than copper but it is quite expensive.

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1) Jute $\rightarrow$ It is made from cellulose which is the major solid constituent of vegetable plants. Its fibres are thicker and is similar to cotton cloth but is cheaper in cost.

2) Impregnated fibrous materials $\rightarrow$

It is by proper impregnation that limitations like hygroscopicity & thermal and chemical degradation of unimpregnated fibrous material are overcome.

3) Impregnated Paper dielectrics :-

4) Amongst all fibrous material used as insulator this class contributes the maximum. The technique of impregnation is complicated. oil used for this purpose are selected carefully depending on requirements.

Main features of impregnated paper insulation are: $\rightarrow$

- Good mechanical properties.
- Good chemical stability.
- Ability to withstand high temperatures.
- Dielectric constant varying betⁿ 2.25 & 4.
- Comparatively less dielectric loss.

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(d) Non-flammable.

Application of impregnated paper →

Major applications of impregnated paper are in →

i) Cables: - in all type of cables i.e. underground power cable, mining cable, and submarine cable in the operating voltage range of 220 V to 100 kV.

ii) Transformer: paper dielectric is frequently used in high voltage power transformer.

iii) Capacitor.

(b) Varnished or impregnated textiles →

cotton or silk textiles can be varnished by two types of varnish: -

i) oil varnishes and

ii) Oleobituminous varnishes. (Commonly

used thickness of varnished textiles vary between 0.08 mm to 0.25 mm.

This material belongs to Class A insulating material.

9 outstanding features of varnished textiles are :-

- 10 i) Good mechanical strength.
- 11 ii) Good dielectric strength.
- 12 iii) Low hygroscopicity.
- iv) Low resistance to organic solvents.
- v) Limiting working temperature of 105°C .
- vi) Open bituminous varnished textiles are not resistant to oil.

1 Application of varnished or impregnated
2 textile : $\rightarrow$

3 This insulation is widely used
4 for windings in electric machines of low
and medium ratings. It is also used on
cables as wrappers and liners.

5 Nonresinous Materials : $\rightarrow$

6 Solid or semisolid insulation which are directly available in nature and are organic based fall under this class. These materials are mineral waxes, bitumens ~~and~~. This defect restricts the use of this class of material to low voltage system only.

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(A) Bitumens → Bitumens are solid materials obtained by refining crude petroleum.

- 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: → It is normally used in electric engineering because of its outstanding property of being water resistant. It is very cheap bitumens find wide application in underground cable box the protection of lead & steel conductors against corrosion.

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(B) Waxes :-

a) Paraffin & microcrystalline waxes

These waxes are obtained by the process of distillation of mineral petroleum oil. These waxes are hydrocarbon in composition.

Special features of these waxes are:-

- i) Easily soluble in mineral & synthetic insulating oil.
- ii) Mechanically weak
- iii) Poor electrical properties which becomes poorer when heated.
- iv) Paraffin waxes get oxidized when they are heated beyond melting point some antioxidants have been used to reduce oxidation.

Application of Paraffin & microcrystalline waxes

The excellent sealing property of waxes makes them fit for use as sealing material. & microcrystalline waxes are extensively used in India for transmission

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(b) Natural Wages: - As the name implies these wages are available in nature. Natural wages are ~~also subject to~~ ^{open} for use, after processing, in the form of ~~provision~~ ^{provision} wage.

→ The melting point of natural waxes may be upto 130°C depending upon the type.

Application of natural waxes →

These waxes are mixed with insulating oils to improve the viscosity ~~of~~
~~proper~~ These waxes also used a se
constituent of Sealing compound.

Insulating Liquids:

6. Insulating linings apart from working as insulation, better other important requirements like:-

a) They are able to improve insulating properties of other solid materials (fibrous specially) by eliminating air & other gases.

b) They offer good dissipation media.

i) They are sometime require both extinguishing arcs in certain application like circuit breaker.

Application of insulating liquids: →

These liquids are finding use in application like capacitors & transformer. However, use of these oil is still comparatively limited because of some defects. Main features of insulating liquids: →

- i) oxidation
- ii) moisture
- iii) temperature
- iv)

The various important insulating liquids are described below: →

a) mineral insulating oil: -

b) Synthetic liquids

c) Miscellaneous insulating liquids

i) vegetable oil

ii) fluorinated liquids

iii) Silicon liquids

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Ceramics :->

Ceramics are material made by high temperature firing treatment of natural clay and certain inorganic matters. Structurally ceramic are crystals and bonded together.

Main features of ceramics :->

The main features of ceramic are :-

i) Ceramic are hard, strong & dense.

ii) Not affected by chemical action except by strong acids & alkalis.

iii) Stronger than compression than tension.

iv) Excellent dielectric properties.

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v) Weak on impact strength.

They can not be used as self supporting thin films like paper, cotton, etc.

Application of Ceramics :-

The capacity to withstand high temperature immunity to moisture and electrical properties which make ceramics valuable for many electrical application.

- a) Porcelain Insulator (T & bushing, bushing)
- b) line insulator pin,
- c) ~~other ceramic materials~~

Mica & Mica Products :-

Mica is an inorganic Material. It is one of the best natural insulating material available. In spite of the tremendous progress made in insulation technology this material & its products still find many application in the present day. It is one of the oldest insulation of outstanding performance. India fortuitously claims the best & biggest reserves of mica in the world.

The quality of mica can be classified on visual basis following two varieties

- i) muscovite mica
- ii) phlogopite mica.

20

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9) Muscovite mica! - Chief sources of

supply are India, Brazil & U.S.A but the best available is India. The basic chemical composition of muscovite mica is $\text{KH}_2\text{Al}_3(\text{SiO}_4)_3$.

12) Some more properties of muscovite mica:

1) Strong, ~~hard~~ tough, & less flexible.

2) Colourless, yellow, silver or green in colour.

3) Insulating properties are very good.

4) Application! - It is generally used where electrical requirements are severe.

6) Phlogopite mica: → Principle sources of

supply are Malagasy, U.S.A & Canada. The basic chemical composition is $\text{KMg}_3(\text{Si}_3\text{O}_{10})_2$. It is also called magnesian mica.

Some Properties:-

i) Amber, yellow, green or grey in colour.

ii) ~~is~~ resistant to alkalis but less so to acids.

Application of mica:- It is used when there is greater need of thermal stability as in domestic appliances like irons, hot plates, toasters etc.

Asbestos & Asbestos Products:-

Asbestos is the term used to designate a class of naturally occurring long fibre minerals. These fibres are strong and flexible and some varieties are even suited for spinning into different textile.

~~can~~ Two types of asbestos are naturally available:-

a) Principal sources of supply are Canada & Africa.

b) Specific gravity 2.0-2.8

c) It is highly hygroscopic. It contains

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about 14% moisture at room temperature.

Amphibole Asbestos:-

a) Principal sources of south africa & Alaska.

b) It does not lend itself to easy spinning because the fibres are either too soft or too hard & brittle.

c) Highly hygroscopic.

Application of Asbestos:- It is used

in low voltage work as insulation in the form of rope, tape cloth & board.
~~It is such uses it is,~~

Glass:- Glass is an inorganic material made by the fusion of different metallic oxides. It is normally transparent, brittle and hard. It is insoluble in water and the usual organic solvents.

Application of Glass: -

- 9
- 10 Glass is used very widely as moulded insulating devices such as electrical bushing, fuse bodies, insulator etc.
- 11 It is used as a dielectric in capacitor.
- 12 Radio & television tubes, electrical lamps, laminated boards etc.

Natural and Synthetic Rubbers: -

- 2 Natural rubber is obtained from the milky sap of special trees. It finds ~~exer~~ very
- 3 limited application in engineering. The reasons are that it is rigid when cold, sticky when
- 4 warm and it gets oxidised when exposed.
- 5 → In common language rubber is a material which is stretchable to more than twice its
- 6 original length without permanent deformation.

Insulating Gases: -

Introduction: → Simple gases eg air and nitrogen, are commonly used in insulators. However, electronegative gases such as Freon Sulphur hexafluoride are now-a-days in use because of certain advantages.

10	Simple gases	Hydrocarbon gases	oxide gases	Electro-negative gases
11	Air	Carbon di-oxide	Methane, Ethane, Propane, etc.	Neon and Sulphur hexafluoride
12	Nitrogen	Sulphur dioxide		
	Hydrogen			
	Helium, etc.			

→ Like other Insulating Material the Selection of a gaseous insulator needs complete knowledge of its dielectric behaviour in the range of temperatures & pressures within which the insulating gas is expected to work.

Commonly used insulating gases:-

Commonly used insulating gases are discussed as follows:-

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Air! - Like other insulating gases, the dielectric constant of air increases linearly with increasing gas pressure.

→ Air acts as an insulator in many electrical application in addition to the solid or liquid insulating

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material provided. common examples
are over head transmission line,
condensers, plugs, switches, various
electrical machine & apparatus etc.

Nitrogen & Hydrogen:-

Like air nitrogen is also commonly
used as insulator in electrical equipment.
In many application, nitrogen is used
both for electrical & chemical purpose.
In many high voltage application air is
replaced by nitrogen to prevent oxidation
of other insulating material & thus to
reduce their rate of deterioration.
For example in oil filled transformer.

Sulphur hexafluoride:-

When Sulphur is burnt in an atmosphere
of fluorine, sulphur hexafluoride is formed.
It has many advantages as an insulating
gas. It has remarkable high dielectric
strength & is non inflammable. It is
characterized by cooling property which
is superior to those of air & hydrogen.

Dielectric Material :-

Introduction :- It was stated that Material which are used for storing of electrical energy are classified as dielectric Material. Dielectric Material are essentially insulating material.

Dielectric constant or Permittivity :-

Consider two insulated conducting Plates forming a capacitor having air in between them. Let the value of the capacitance be C_0 . If a piece of another dielectric, say glass, is introduced in the space between the two plates it is observed that the value of the capacitance increases. Let the value of the capacitance in this case be C . Since the value of the capacitance of a capacitor is defined as the charge storing capacity, it is obvious that the charge storing capacity of the condenser increases when air is replaced by another dielectric in the case glass.

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

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Polarisation :->

It has already been stated that Polarisation of dielectric is analogous to Magnetisation of Magnetic Material. If a slab of dielectric placed in an electrostatic field it will undergo Polarisation. Polarisation is defined as the definite orientation of electrostatic dipoles in a material due to an applied electric field.

Dielectric Loss :->

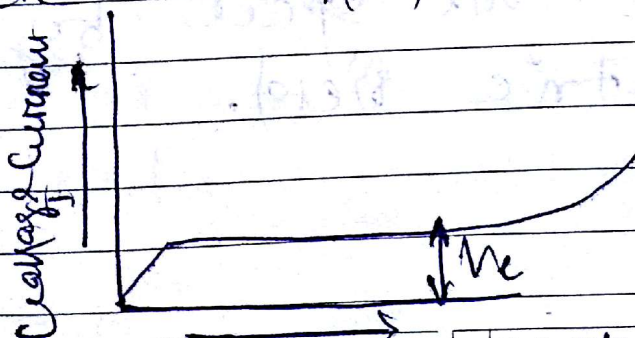
In the case of electronic Polarisation the electrons undergo only very little displacement & remain within the limits of their atoms or ions. Electronic Polarisation is set up within extremely small time. Even by the time a half cycle of an alternating field is completed the electrons are able to shift to their extreme position. Electron displacement in this type of Polarisation is elastic in nature.

→ In the case of Polar dielectrics the orientation of the dipoles in the electric field is not a pure elastic displacement process. It involves overcoming of certain internal friction forces on which certain amount of energy is expended. This amount of energy is known as dielectric loss.

Electrical conductivity of Dielectrics and their Breakdown →

Gaseous Dielectrics → The electrical conductivity of all gaseous dielectrics is identical. Air is the most commonly used gaseous dielectric. The primary constituents of air are Nitrogen and Oxygen. Under the influence of various natural ionizing factors eg cosmic rays and ultra violet rays some ionization takes place in air.

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



Liquid Dielectrics:-

All liquid dielectrics easily get contaminated with some impurities in the form of solid particles which become suspended in such dielectrics. Another contaminant in hygroscopic liquid dielectrics is water. All these contaminants give rise to conductivity called impurity conductivity.

Solid dielectrics: → Electrical conductivity of

Solid dielectrics may be ionic, electronic or combined (ionic plus electronic) in nature. As in the case of liquid dielectrics, the electrical conductivity of solid dielectrics also depends upon presence of various contaminants or impurities.

A Breakdown in a contaminated dielectric may occur due to the formation of conductive bridges between the electrodes by the contaminant drawn into inter-electrode space by the applied electric field.

→ Breakdown in solid dielectrics may commonly be either electrothermal or electrical depending upon the prevailing conditions. Electrothermal breakdown caused by the destruction of the dielectric due to heating produced by dielectric losses. Solid dielectrics are poor conductors of heat.

Properties of Dielectric →

Application of Dielectrics →

It has been mentioned earlier that the function of dielectric is to store energy. The most common example of the use of dielectrics for the purpose of storing energy is in capacitors. Capacitors are generally classified according to the kind of dielectric used in them. Broadly capacitor may be grouped into two types:

- i) capacitor that use vacuum / air or other gases as dielectrics.
- ii) capacitor in which the dielectric is a mineral oil.

ii) Capacitor in which combination of solid and liquid dielectric such as paper, films or synthetic materials, glass, mica etc & mineral oil silicone etc are used.

iv) Capacitor with only a solid dielectric such as glass, mica, titanium oxide etc

→ The first type of capacitors are used in application where energy loss in the capacitor must be small and where the value of capacitance needed is not very large. The dielectric losses in vacuum, air and other gaseous dielectric very small. Such capacitors are used in radio frequency circuits and in low frequency measuring circuits where precision is highly desirable.

Electrolytic Capacitor : →

Electrolytic capacitor make use of electrolytic material as polarizing agent. Electrolytic capacitor are fixed value capacitor. They are polarized device with high capacitance ratings normally used for bypass, coupling and motor starting application.

Magnetic Material

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

→ The Property of Material by virtue of which it allows itself to magnetized is called Permeability. For most material, 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 & equal $4\pi \times 10^{-7}$. The permeability of air is almost same as for free space i.e. $4\pi \times 10^{-7}$.

→ materials which can be magnetized are called magnetic material for such materials permeability μ is given by :-

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

Where μ_r is called the relative Permeability.

→ From the study of electromagnetism. It is known that in free space the magnetic flux density, B is related to the intensity of magnetization,

H, as follows:

$$B = \mu_0 \times H$$

Where B is measured in wb/m^2 & H in
ampere-turns/mm.

$$\mu_0 = 4\pi \times 10^{-7}$$

It has been found that if the same
magnetic intensity, H , which was applied
in free space as mentioned above is now
applied in a solid the resulting magnetic
flux density, B , has different values than
that obtained expression. This means that
in a solid the value of permeability is
different from μ_0 & may be expressed
as μ . Thus in a solid material:-

$$B = \mu H$$

where $\mu \neq \mu_0$

may be written as:-

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

M in expression is called the Magnetization of
the solid.

Therefore the Magnetization is Proportional to the applied field. Thus :-

$$M \propto H$$
$$M = \chi H$$

Where χ is the constant of proportionality & called susceptibility.

Substituting expression we have

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

$$B = \mu_0 \mu_r H$$

Where $\mu_r = 1 + \chi$ is called the relative permeability of the medium. For a non-magnetic material $\chi = 0$ i.e. $\mu_r = 1$.

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Classification of Magnetic Material:-

The materials can be classified into non-magnetic and magnetic materials. Non-magnetic materials are those which do not respond to an external magnetic field. Materials are classified into Diamagnetic, Paramagnetic & ferromagnetic materials depending upon the manner in which they respond to external magnetic field. Diamagnetic & paramagnetic materials fall in the category of non-magnetic materials. Ferromagnetic material are classified as magnetic.

Diamagnetism: → There are many materials in which the cancellation of magnetic field due to electrons rotating in opposite direction in the various orbits of the atom is total.

→ 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.

→ This makes diamagnetism unimportant for electrical engineering applications.

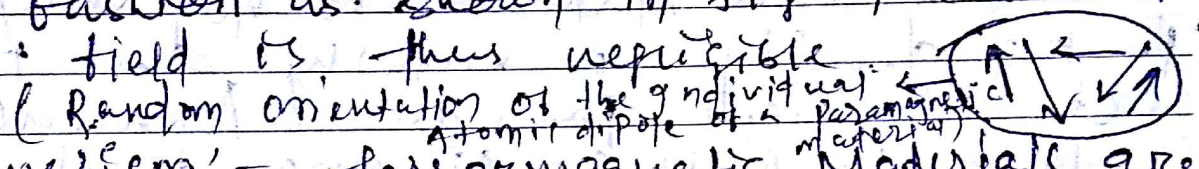
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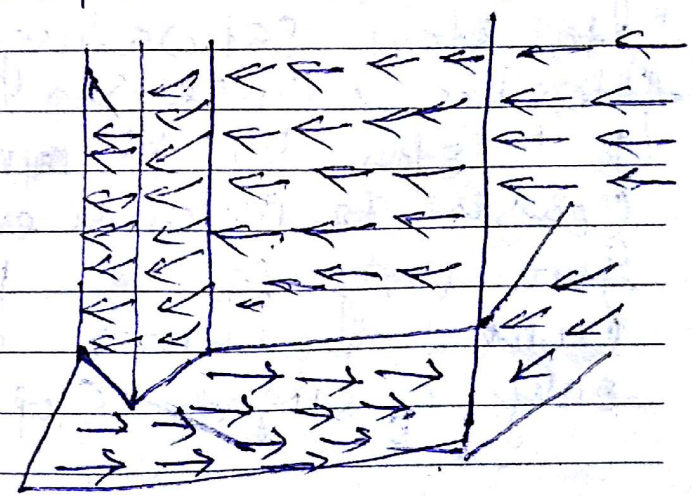
therefore further explanation of diamagnetism is not considered necessary for the purpose of this course.

Paramagnetism: →

Many materials have small but positive relative permeability. Such materials are called ~~po~~ paramagnetic. In such materials the individual atomic dipoles are oriented in a random fashion as shown in fig. The resultant magnetic field is thus negligible.



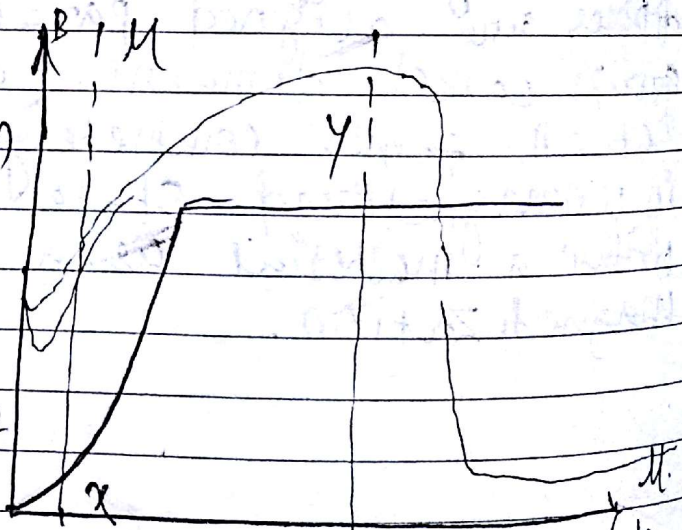
Ferromagnetism: - Ferromagnetic materials are generally crystalline solids. The permanent atomic dipoles are aligned parallel to each other within groups called domains. Each domain is therefore at all times completely magnetized. However in unmagnetized state, the various domains within a material as a whole have zero magnetization.



Magnetisation curve:-

With very weak external applied field H , the flux density, B , rises in direct proportion (i.e. as a straight line from the origin). This means that during this region upto the point x , the domains of the ferromagnetic material do not orient themselves parallel to the applied field and therefore, the material is not magnetized. The flux density is entirely due to the external field. Thus the permeability, $\mu = B/H$ is ~~the~~ slope of the $B-H$ curve of the material upto the point x known as

→ When the magnetization curve reaches the point y , the material is said to start saturating. After this, increases in B is slow till it almost ceases to increase even for very large increase in H , and curve becomes almost horizontal with only a slight slope upwards.



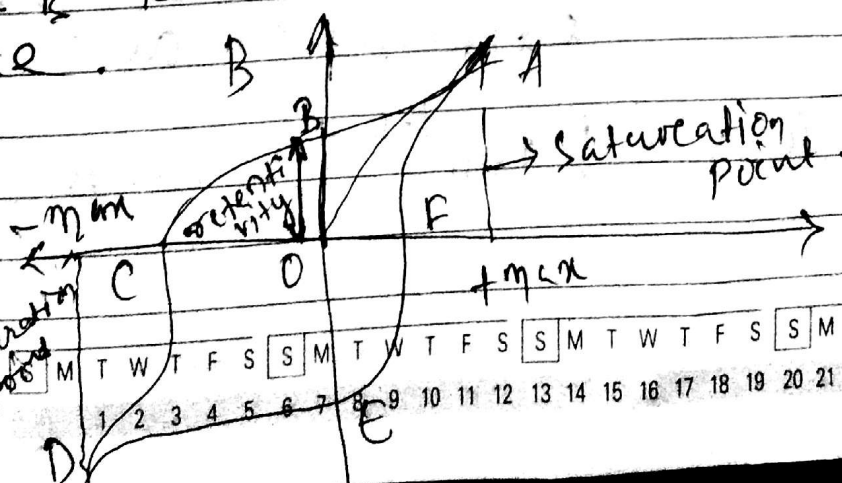
Hypertension $\rightarrow$

→ In a ferromagnetic material, the flux density B increases when external field applied to it is increased. When saturation arrives, the increase in B almost increase even though H may be increased.

→ ~~At this point~~ It now the external Magnetic field is gradually reduced it is found that the original curve OA is not retraced. At H equal to zero the Material is still Magnetised and the flux density has the value O_C . This is called the remanent flux density or the residual magnetism.

→ In order to demagnetize the material completely the external magnetic field H must be reversed and when it ~~reaches~~ reaches the value OD in the reverse direction it is now zero. The applied magnetizing force, H in reverse direction (in this case equal to OD) which cause B to be zero is called coercive force.

$B \uparrow$ ~~$H \uparrow$~~ $H \uparrow$ $B \downarrow$



$A \uparrow B \downarrow$
we $\rightarrow$
Permanent magnet.

→ The results of which represented in figure shows that B always lags behind H. This property of B lagging behind H is characteristic of the magnetic behaviour of ferromagnetic material.

→ When H is taken from positive maximum through zero to negative maximum and then through zero again back to positive maximum the graph relating B & H draws a loop A C D E F B A this is called hysteresis loop.

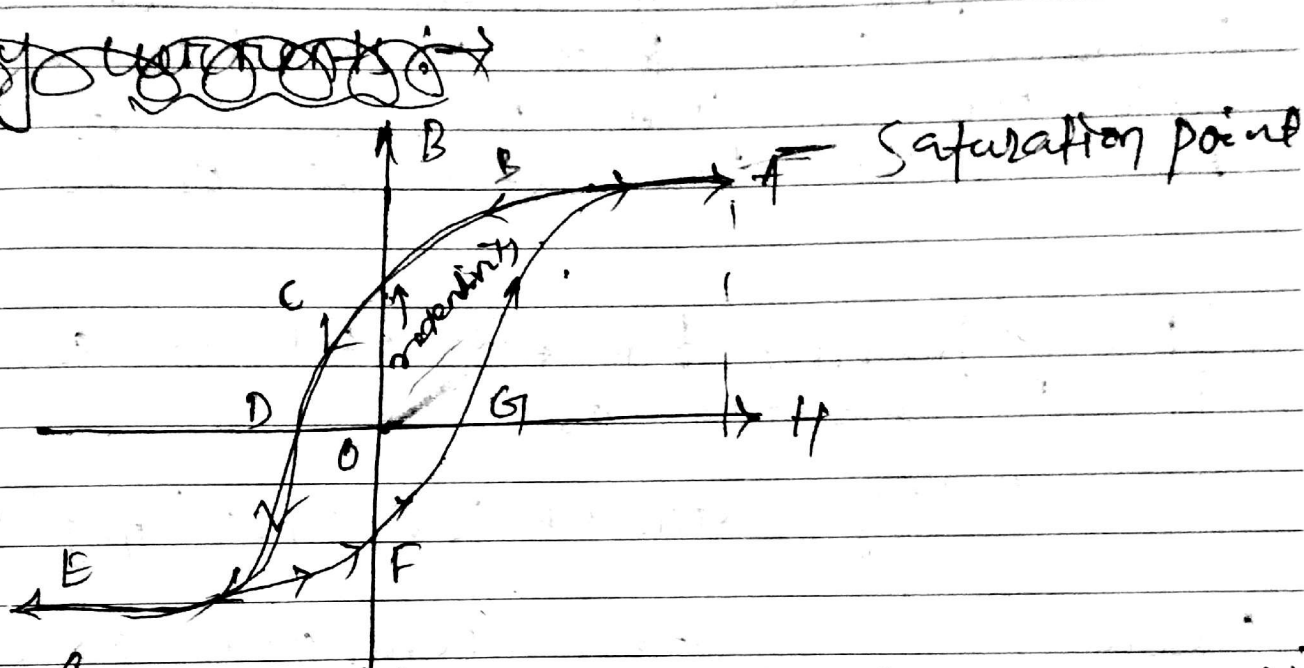
→ Magnetic core for use in alternating magnetic field like those for transformers & rotating electrical machine are made from material whose hysteresis loop-s are narrow in order to keep down hysteresis loss.

→ Hysteresis loss depends upon flux density and frequency of variation of the flux and can be expressed as :-

Hysteresis loss :- $k B_m^{1.6} f$ v watts.

→ where k is constant whose value depends upon the core material, B_m = maximum flux density.

f = frequency of variation of flux
 V = the volume of the core material in m^3 .



(Hysteresis loop for a ferromagnetic material)

Eddy currents →

→ Magnetic material placed in alternating magnetic field also have eddy current induced in them. This is because the material is subjected to rate of change

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of flux linkage & in accordance with Faraday's law of electromagnetic induction, e.m.f.s are induced in the material causing currents, called eddy currents, to flow in the material. These currents cause loss of energy ($I^2 R$ loss in the material, where I is the value of eddy current and R is the resistance of the eddy current path provided by the material. This results in the heating up of the material.

The expression for eddy-current loss can be represented as :-

$$\text{Eddy current loss} = k \cdot B^2 m f^2 t^2 v_c \text{ Watts}$$

Where k is another constant which depends upon the core material & t is the thickness of the core lamination.

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CURIE POINT : →

There is the critical temperature called Curie point above which the ferromagnetic material lose their magnetic properties.

Magnetostriction : →

It has been established that when ferromagnetic material are magnetized a small change of dimension of the material takes place. There is small ~~and~~ extension with corresponding reduction of cross-section of the crystal of which the material is made. Magnetostriction is the major cause of hum in transformers & Chokes.

Soft & Hard magnetic materials : →

→ All ferromagnetic materials are divided into two broad group :-

- Soft magnetic material &
- Hard magnetic material.

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9 ~~It is the commonest soft magnetic~~

10 → Narrow hysteresis loop and conse-
11 quently small energy losses during
cyclic magnetization are called soft
magnetic material.

12 → ~~soft magnetic material~~ The commonest
soft magnetic material are soft iron,
1 nickel-iron alloys & soft ferrites.

2 → Large hysteresis loop area &
3 consequently large energy losses for
each cycle of magnetization are called
4 hard magnetic material.

5 → Such material are therefore used for
making permanent magnets. Carbon
6 steel, tungsten steel, cobalt steel,
alnico, hard ferrites for example of
hard magnetic material.

Soft Magnetic Material:-

Pure iron:- By the term of pure iron it
meant of ferrous material with an extra
low carbon content. ~~The example of low~~
~~carbon steel and electrolytic iron.~~ In low
carbon steel carbon content is less than 0.1%.

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→ Technically pure iron is widely used in many kinds of electrical apparatus and instrument as magnetic material core for electromagnets, component for relay electrical instrument etc. Pure iron is ~~not~~ not used in rotating electrical machine where rotation of the slotted rotor cause variation in reluctance & therefore of flux.

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

Nickel iron alloy:-

The important alloys in this category are Permalloy, Superalloy, and Mumetal.

Permalloy:- This is used in manufacture of sensitive relay. The Curie ~~temp~~ temperature of this group of material varies between 420 to 580°C depending on the percentage of nickel content and

heat treated upto about 1050 to 1100°C .
 9 It has initial permeability varying between
 2500 to 8000 where as maximum permeability
 10 reaches as high as 100,000.

11 Superalloy: $\rightarrow$ It consist of iron &
 nickel alloyed with copper and
 12 molybdenum. This alloy is distinguished by
 its high initial permeability upto 100,000.

1 Mumetal: - It consist of iron and nickel alloyed
 2 with copper and Chromium. It is used
 for manufacturing instrument transformer
 3 and miniature transformer (used in
 communication circuitries). It is heat
 4 treated upto 100°C & having a curie
 temperature of 130°C . Its initial
 5 permeability is 20,000 & maximum permeability
 6 is 110,000.

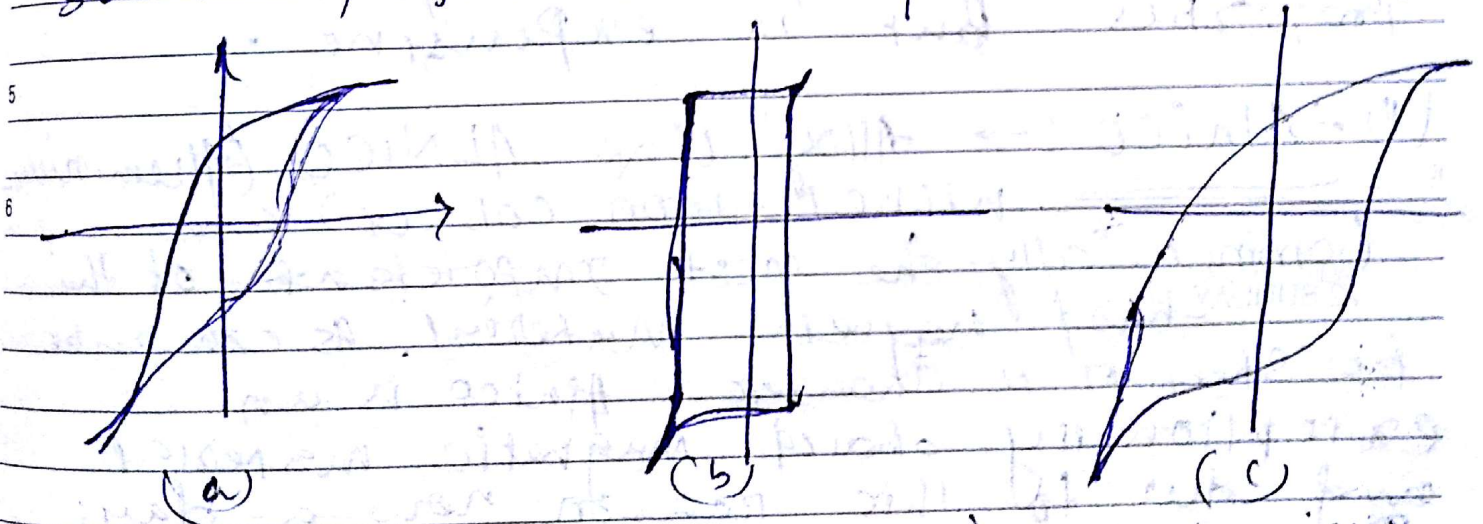
Soft ferrites: $\rightarrow$ Ceramic Magnets, also
 called ferromagnetic ceramic
 and ferrites, are made of an iron oxide,
 Fe_2O_3 , with one or more divalent oxide
 such as NiO , MnO or ZnO . These magnets
 have a square hysteresis loop & high
 resistance to demagnetization & are valued
 for magnet for computing machine.

where a high resonance is desired.

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

Hard Magnetic Material:-

Hard magnetic materials are used for making permanent magnet. The desired properties of material required for making permanent magnet are high saturation values, high coercive force and high residual magnetism. Typical hysteresis loops for soft and hard magnetic materials are shown in fig for comparison.



- Soft magnetic materials such as Silicon Steel.
- Soft magnetic material such as Permalloy.
- Hard magnetic material.

(i) Carbon steel tungsten steel cobalt steel

Soft magnetic material cannot be used for making permanent magnet because they have narrow hysteresis loop. It has been seen that carbon when carbon is added in a material, its hysteresis loop area is increased. That's why in early days carbon steel was used for permanent magnets.

→ When a material like tungsten, Chromium or cobalt are added to carbon steel its magnetic properties are improved. cobalt steel has exceptionally superior magnetic properties but is expensive.

(ii) Alnico → Alloy like ALNICO (Aluminum, nickel-iron, cobalt) are

commercially the most important of the hard magnetic material. Its composition is Fe 17% Co 24% Al 11% Ni 11% Cu 1% C 0.05%. Alnico is an exceptionally hard magnetic material and due to this reason now-a-days permanent magnets are most commonly made of Alnico.

High quality Permanent Magnet are used in many electrical engineering application as in various electrical measuring instrument.

Hard ferrites :- Hard magnetic ferrites like $\text{BaO}(\text{Fe}_2\text{O}_3)_6$ are used for the manufacture of light weight permanent magnets due to their low specific weight.

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