Material

Conducting 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 ohms law $V = IR$

Thus $R \propto l$

$R \propto \frac{l}{a}$ OR $R\uparrow$ $a\downarrow$ inversely. $R\uparrow$ $l\uparrow$

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

Where "ρ" is the cofficeant of proportionally and is called the resistivity or specific resistance of the material.

R : Resistance of material

r : 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 factor which affect the value of resistivity of a material are temperature, alloying, & mechanical stressing.

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 cofficeant.

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

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

where R_t & R_0 are respectively the resistance of the conductor at t_0 & $0°C$ & α is the temp. cofficeant is the resistance of the same material at any other temp. t_1 be R_{t1} then the eqn become :-

$$R_{t1} = R_0 (1 + \alpha t_1) \quad \text{---} (ii)$$

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

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

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.

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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 lying 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. It therefore may be

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used for making structural product such as rods, shafts, plug points, socket out-let, knife, 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 hot 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 & decrease the conductivity.

Classification of conducting material :- (i) Low (ii) High

(i) Low resistivity material are used in house wiring as conductor for transmission & distribution. In winding of the 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:→ copper, Aluminium.

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

Properties of low resistivity :→

(i) Low temperature cofficeant :-

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 have high temperature cofficeant of resistance then the voltage drop & power losses will be high.

(ii) Sufficeant mechanical strength :-

The conducting material used for the winding of transformer motors and generator developed mechanical forces when loaded which can become very large in a high current flows due to short circuit. The conducting materials should posses 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 jointed. The joint should be offer minimum contact resistance results of the joint is soldered.

Resistance to corrosion :- The conducting material should be that it is not coroded when used in outer atmoesphere

(2) High resistivity Material :-

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

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

Properties :→

(i) Low temp. coefficient :→

High resistivity material are used as shunts in electrical measuring instrument. 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 heater, furnaces.

(iii) No tendency for oxidation :- material used as high resistances 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 incase of wire, wound resistor but incase of ovens, heaters, starters

Thin wire 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 break-down during the operation.

Low Resistivity Material & their application!

(i) Copper :→ Amongest all the conducting materia 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 become soft after annealing process invol ves heating at a specific temperature & then cooling after annealing copper is tem

* Resistivity of ~~hard~~ annealed copper is 1.72×10^{-8} ohm

* Resistivity of hard copper is 1.78×10^{-8} ohm at 20° 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 varries from 8.15 to 4.72 to 4.72 tonnes/cm^2

copper can easily be soldered & welded which are necessary in electrical wiring Annealed copper is used in Insulated conductors in low voltage power ~~angers~~ 14 SUNDAY cables, winding wires for electrical machines, transformers, flexible wire & in making coil for many purpose.

The availity of copper has becomes decreases in India. copper in pure form is not much used an electrical contact material, when 10% - 30% of nickale 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 lower its efficiency.

(ii) SILVER :→ Pure silver has high electrical conductivity in order 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 an 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.

Anneal : slow process of metal heat to cert.

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

(iv) Aluminium :→ Aluminium is widely available and used extensively in the field of electrical energy. its resistivity is 2.8 × 10⁻⁸ ohm i,e about 1.6 time higher than copper.

* Density of aluminium is 2.68 which means that aluminium is much light 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 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 assume 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) mild steel → 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 then 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 crossection is used it becomes rigid in construction & breakdown while handling to avoid this conductor are made of no of thin wire (strands) together called as strands. stranding makes the conductor flexible and eliminates its breakdown.

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

Bundle conductor :→

The adoption of bundle conductor ~~for high~~ in extra high power transmission enables ~~stran~~ stranded conductor to employed & gives an increased current carrying capacity compare with a single conductor of equivalent crosssectional 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 then copper. it can be easily shaped by pressing it is weldable & solderable.

uses :→ Plug points, socket outlets, switches, fuse holder.

Bronze :→ copper when alloyed with tin (8% to 16%) & a very small percentage of third element like gallium, barillium, phosphurus, silicon is called as 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 passes high mechanical strength ie compare to copper but have lower conductivity.

~~Phosphor~~ 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 current 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 it 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 on consist of grinding of raw materials, then mixing the powder carbon

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

~~characteristics~~ use of Carbon:→

Carbon is used in the application like brushes for electrical machine & apparatus, electrical, non wire resistor & some other ~~tele~~ 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.

21 SUNDAY iii) Pressure sensitive.

iii) **Platinum:→** Platinum is greyish white metal it is ductile. Platinum is a heavy metal having specific weight 21.4 gm/cm^2.

i) The resistivity of Platinum is 0.1×10^{-6} ohm.m

ii) Its melting point is 1775°C.

iii) Its temperature cofficeant is 0.0030°/C
Platinum can be drawn into thin wires & strips.

(iv) **Mercury** :→ Mercury is a heavy silver white metal. Its specific ~~Simmer~~ weight is 13.55 gm/cm². Its boiling points is 357°C. ~~Its resistivity~~

i) Its resistivity & temp cofficeant of resistance are respectively 0.95×10^{-6} ohm m. & 0.00027°C.

Mercury is very poisions : It is used in the rectifier, gas filled tubes, electrical switches.

Super conducting Material :-

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

Application of ~~Semi~~ Super conductor Material :-

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

Machine & transformer utilising super conductivity.

Power cables :- Super conducting material is used for power cable will 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 solinoid which do not produce any heat during operation have been produced it has been possible to design electro magnet using super conductivity for use in laboratory & for low temperature devices like the Maser.

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 achive low temperature required for super conductivity. Because helium being an expensive gas efforts are being made to devlop compounds which exhibits super conductivity at temperature to be obtain by the easily available.

9 Superconductivity :→

10 It has been stated earlier that
11 the resistivity of most metals increases with Increase in temperature. and
12 vice versa. There are some metal & chemical compounds whose resistivity
1 becomes zero when their temperature brought near 0° Kelvin ~~At~~ - (273°C).
2 At this stage such metal or compounds are said to have attained Superconductivity.
3
There are two types of superconductor
4 commonly known as type-I & type-II superconductor. Type-I superconductor are
5 soft superconductor ~~where~~ where as Type-II superconductor are hard super-
6 conductors.

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(Semiconducting Material)

Semiconductor:-

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

Electron Energy & Energy Band Theory:-

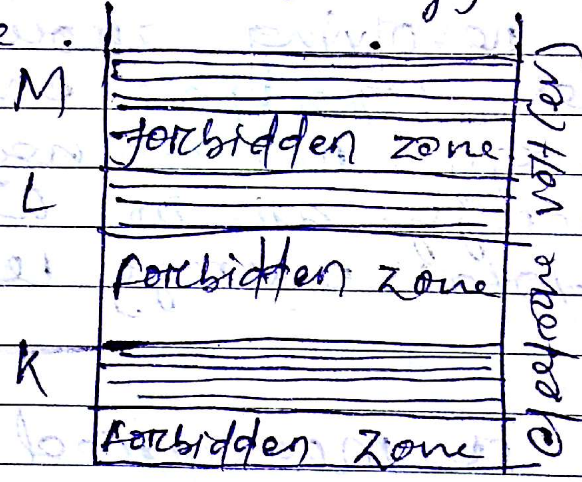
→ An electrone revolving around the nucleus of an atom has potential energy, centrifugal energy, rotational energy, & magnetic energy all of which together determine the total energy level of the electrone.

→ This value is measured in electrone volt (ev).

→ The electrone volt is defined as that amount of energy gained or loss when an electrone moves with or against a potential difference of 1 volt.

→ The larger the orbit in which an electrone revolves the greater is its energy -electrones with least energy closes to the nucleus each level containing electrone with higher energies.

→ The energy level 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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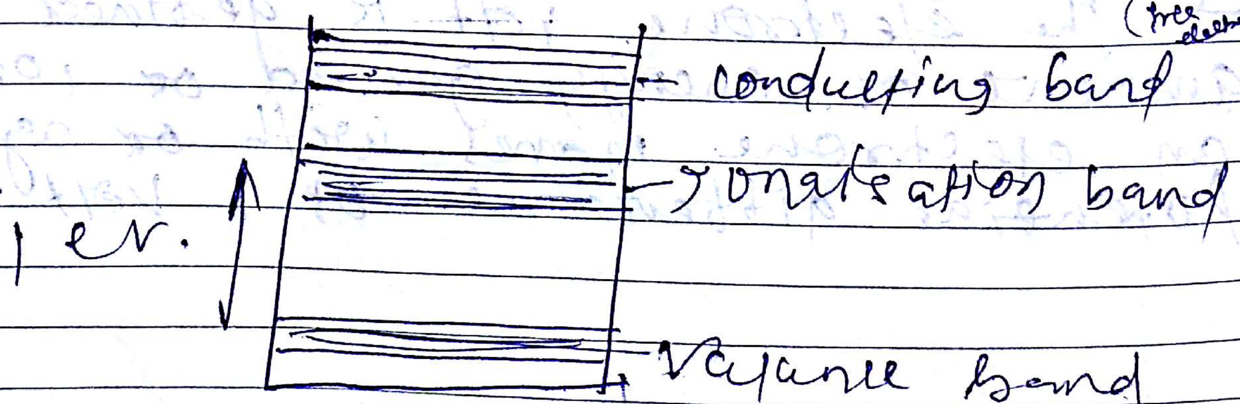
Excitation of Atoms:-



Energy band representation Of Ionaisation :→

When each electrone in an atom is its normal orbit The atom is said to be in an unexcited state. To move an electrone further away from the nucleus. required some additional energy. The additional energy can be obtain from Source like light, heat, electrostatic, magnetic kinetic energy.

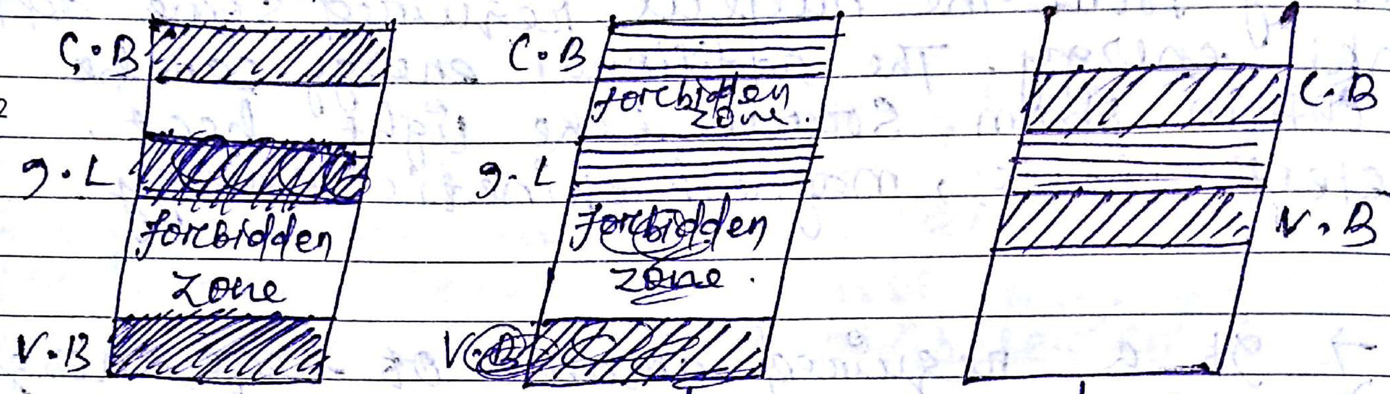
→ If a required amount of heat energy is observe by electrone it will jump to higher energy level. So the atom is said to be an excited state.

→ When the required amount of light or heat energy is observed by valance electrone. It will leaves the valance band and may move up to ionaisation level. If it does it is realeased 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 electrone.

→ The word ionaisation level is used because when an electrone leaves the valance band the remaining atom is no longest nuetral.

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

Insulator, Semiconductor, & Conductor:-



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 in case of insulator this indicates that electrons in the valance band required large amount of additional energy to move up and becomes free. long as the valance electrons are unable to move upto the conduction band there can be electrons 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.

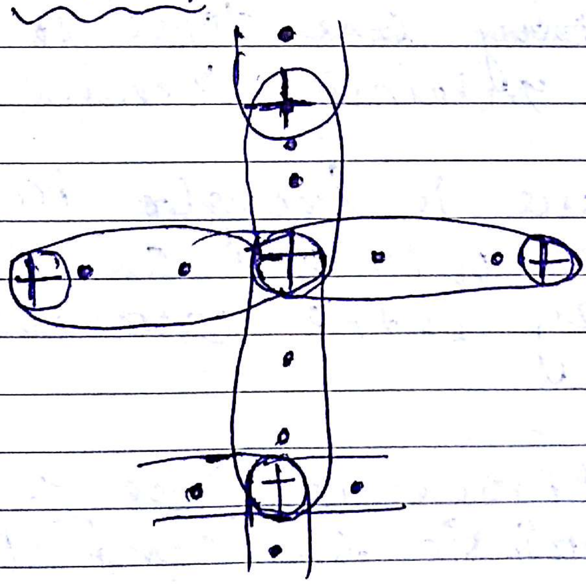
→ Incase of conductor their is no gap between the valance band and the conduction band In some better conductors the conduction & valance band may overlap.

Semiconductor material :-

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

Insulator → v.e → 8
Semiconductor → v.e → 4
Conductor → v.e → 1.

Covalent Bond :→



→ A covalent bond results when each atom in order to fill its valance ring with 8 electrone, shared electrone is called as covalent bond. Each bond with two electrone is an electrone pair bond.

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

Intrinsic Semiconductor :→ (undoped or i-type) n=p

→ If a crystal eg:- silicon or germanium does not contain any impurity atoms i.e if 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 electrone is free from an atom of an intrinsic semiconductor material it breakes a covalent bond & leaves behind a vacancy that is called as hole.

→ The free electrone & the hole from an electrone hole pair the higher the temprature the greater the number of free electrone.

Extrinsic semiconductor :→ .

→ Pure form of meterial called as a extrinsic semiconductor.

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

→ We must add certain impurities to the semi-conductor 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 electrone & is called the pentavalent group.

eg :→ Germanium, Arsenic, Antimony, phosphorus.

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9 Majority & minority carrier:→

10 → In N-type Material conduction take places through the free electrone. That free electron are called majority carrier.

11 → The holes being small in number so it is called
12 as minority carriers.

1 Semiconductor Material:→

2 There are 11 semiconductor material in the Periodic table:-
3

Boron, carbon, silicon, germanium,
4 Arsenic, Phusphorus, Antimony, sulphure, Selinium, Tellinium, & Iodine.
5

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

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

1 → Illumination.
2 → voltage.
3 → Electric field.

→ Semiconductor can be classified as :→

(i) Monocrystal with an atomic lattice structure like carbon, silicon, germanium, & poly crystal with molecular lattice structure like Selenium, Tellurium, Antimony, Arsenic Phosphurus.

(ii) Oxide of such metal as copper, zinc, cadmium, Titanium, Tungsten, Molydenum.

(iii) Sulphides, copper, Cadium, & other element.

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

→ When an external voltage applied across two material a flow of current takes place. If the possitive & negetive 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 possitive of the supply connected to the N side there negetive 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 rectifier use germanium or silicon as semiconductor material.

→ Germanium rectifier where invented earlier then silicon rectifier.

→ Germanium has melting point of 958°C & silicon 1415°C.

→ Germanium & silicon semiconductor find wide use in high frequency. germanium & silicon rectifier can operate at high current densities & reverse voltage with efficeancy about 98%. silicon rectifier can be operate by 200°C.

Copper Oxide & Serinium 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 the copper. The second electrode is soldered to the cuprous oxide film. when possitive potential is applied to the oxide layer & negetive to the copper i.e correspondance to forward biased in Pn junction.

Thermistor or temp. sensitive resistor :→

Increasing the temprature of semiconductor material causes there resistance to decreases. 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, Ireon zinc.

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

Photoconductive cell :→

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

eg :→ Alarams, Smokedetector, & control for Street light.

Photovoltaic cells :→

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

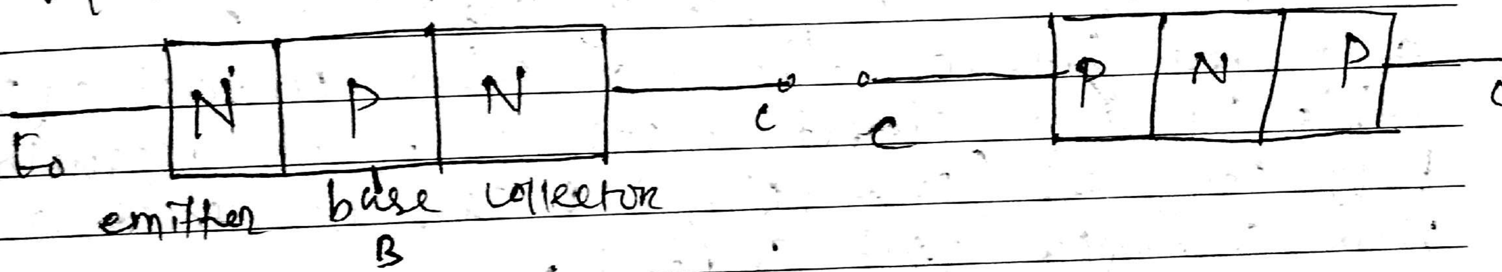
Varistors :— (Varisters)

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

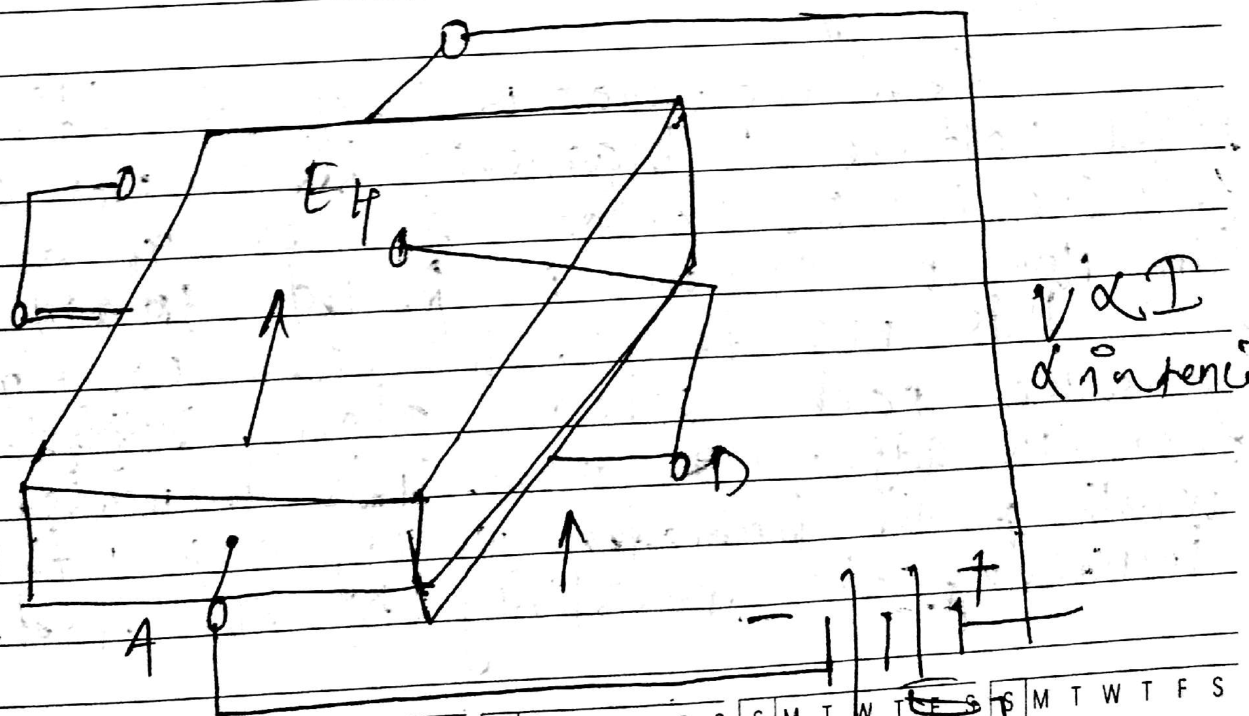
eg :→ voltage stablizer, Motor speed controller.

Transistor :→

The restistance of semiconductor depends to a large extend on the magnitude of the electric field. The current in a semi-conductor does not follows ohms 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 or N-P-N material.



Hall Effect generator :→



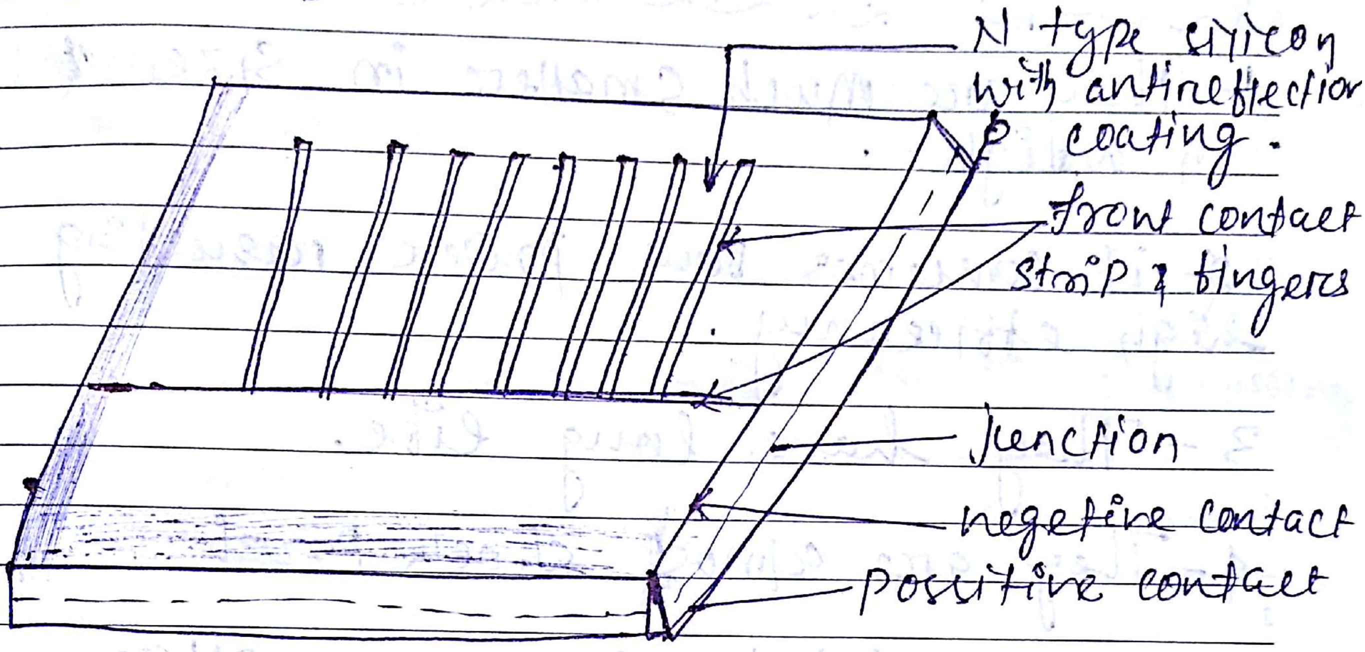
When a current flows through a semiconductor bar placed in a magnetic field a voltage is developed at right angle to the both the current & the magnetic field. This voltage is proportional to the current & the intensity of the magnetic field this is called as hall effect.

Consider a semiconductor bar which has contact have four sides. If a voltage E_L 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 contact C & D. This E_H is a direct measure of the magnetic field strength (intensity) & can be detected with a simple volt centre.

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 increase 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 with~~ 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 20mm x 20mm x 300 M.M The ~~NP configuration is obtained by diffusing~~ 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.

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Insulating Material

Any material that is able to insulate or to prevent the flow of electricity through it, when a difference of potential 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 property are :-

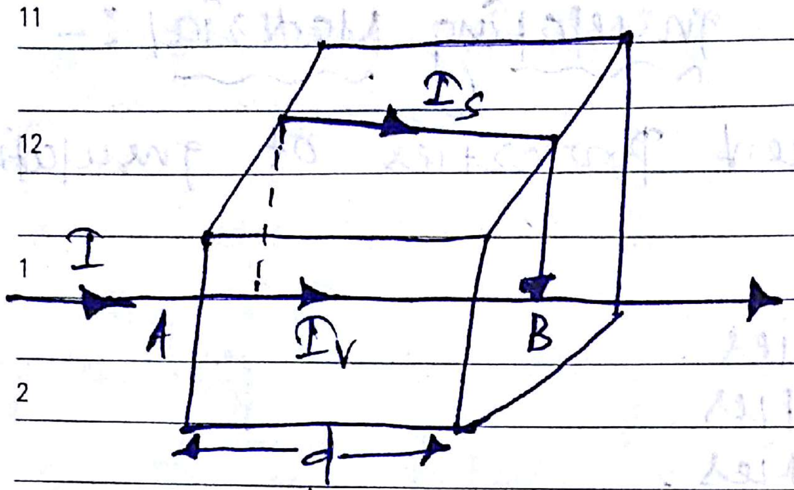
i) Insulation resistance = $R = V/I$
ii) dielectrical strength
iii) die-electric loss.
iv) die-electric constant.

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

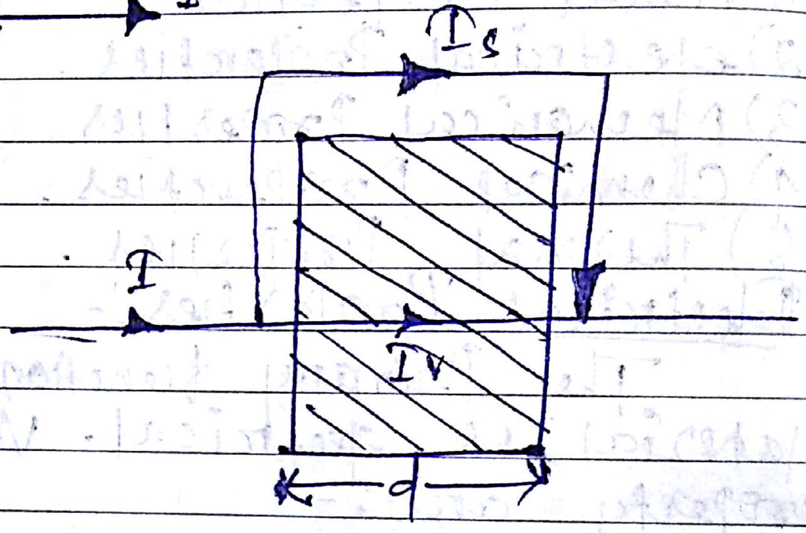
An insulator to which a voltage 'V' is applied

9
10
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.

11
12
1
2
3
4
5



(b)



(a)

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

(a) Volume Resistance :-

The resistance offered to current I_v 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 :-

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

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.

(b) Surface Resistance :- The resistance offered to current I_s which flow over the surface is called surface resistance it depends upon the humidity.

(ii) Die-electric Strength :- Every electrical apparatus is design & there should be operate within a define range of voltage. If the operating voltage is increases gradually

Some value of voltage breaks down will occur which spoiling the insulation property permanently in solid insulating material. But not necessary in liquid or gaseous insulation material. The property which attributes to such type of breakdown is called as die-electric strength. Die-electric strength is the minimum voltage which when to apply to a insulating material will result in the destruction of the insulation properties. It can be expressed as volt/unit.

Difference betn material & Die-electric strength:-

Material	Die-electric strength (kilovolts/m)
1- Natural rubber	24
2- synthetic rubber	4.0 - 36
3- Asbestos (paper base/laminate)	3.5 - 4
4- Mica	80
5- High voltage porcelain	10 - 16 KV
6- low voltage porcelain	1.5 - 4

Factor effecting 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.

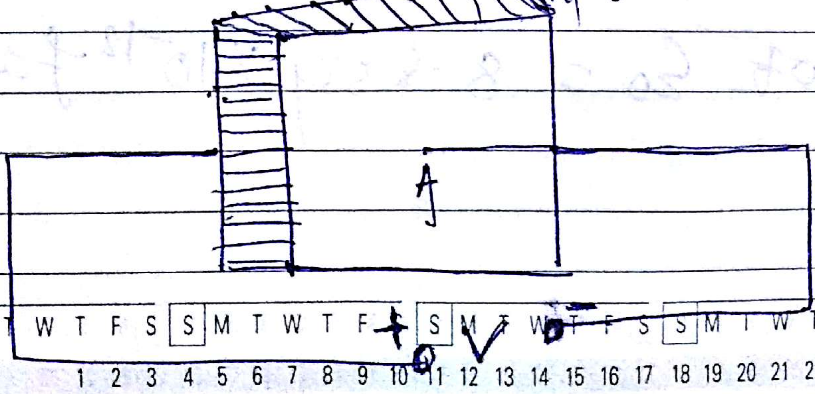
Die-electric constant:-

C = Capacity, capacitance.

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

$\Rightarrow Q = CV$

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



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

The capacitance can expressed by :—

$$C \propto A/d$$

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

Where A = face area of insulation

d = distance between the insulation

ε = die-electric constant or permittivity.

Also, $\boxed{\varepsilon = \varepsilon_0 \varepsilon_r}$

Where ε_0 = die-electric constant of the vaccume.

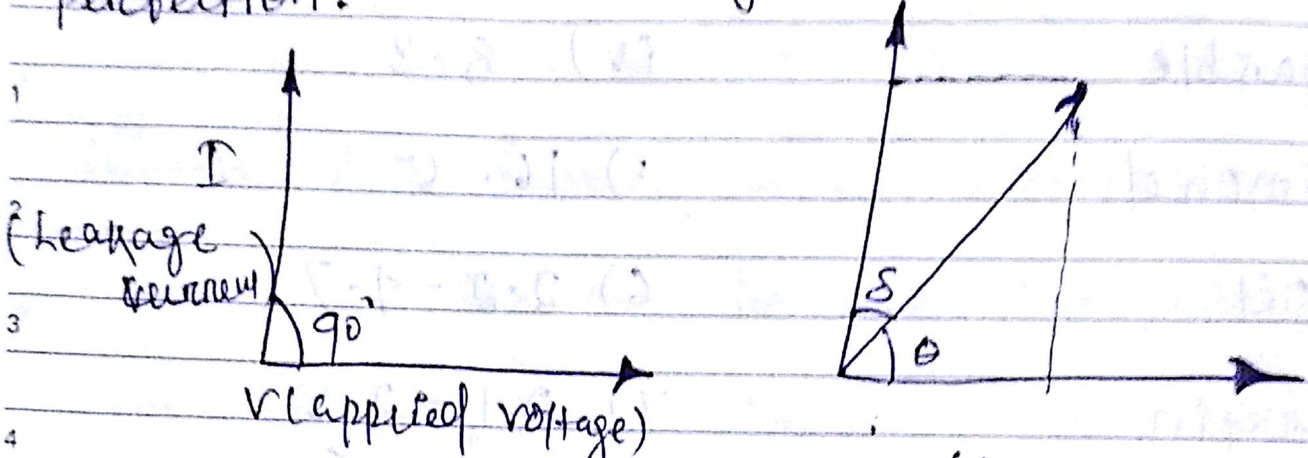
ε_r = die electric constant of the material.

Value of $\varepsilon_0 = 8.854 \times 10^{-12}$ farad/m.

Matercial	Die-electric constant (ε_r)
1) Paper	i) 2.0
2) Mica	ii) 2.5 – 6.6
3) Glass	iii) 5.4 – 9.9
4) Marble	iv) 8.3
5) dimond	v) 16.5
6) Oil	6) 2.2 – 4.7
7) Parafin	7) 2.1 – 2.5
8) Porcelin	8) 5.7 – 6.8
9) Rubber	9) 2.0 – 3.5
10) Wood	10) 2.5 – 7.7
11) Water	11) ~~[illegible]~~ 70

Die-electric 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.



(a) (b)

Phase Relation betn leakage current & applied voltage in Dielectrics.

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.

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 increases causes increased die-electric loss.

Visual Properties :→

The following are the visual properties of insulating materials.—

a) Appearance.
b) colour
c) Crystallinity

These properties are not of any significant importance from engineering & therefore form 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.

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Mechanical Properties :→

The Property affecting the selection of Insulator 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 in equipment ~~Strength requirement~~ for example strings of suspended porcelain insulator have to bear a good 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) Temprature rise :→ Temprature 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

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

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

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.

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 & overloading current limitation.

(iii) Ambient temperature & maximum temp. of insulation can withstand. discussed

Various thermal properties are given below:-

Melting Points, Flash Point, Voltality:→

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

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

→ Voltality assumes importance from the fact that when a trapped gas is evolved from a volatile insulating material

subjected to voltage stress, the breakdown
9 is very rapid. A volatile material can not be
good insulator.

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

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

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

Chemical Properties :→

Chemical Resistance :→

Presence of gases, water, acids, alkalis
& salts affects different insulator differently.
Chemically a material is a better insulator
if its resist chemical action.

Certain plastic are found approaching this condition.

Classification of insulation material of the basic thermal stability in service:-

Class	Maximum working Temperature	Material or combination of mat.
Y (formerly O)	90°C	cotton, silk, paper, Press, press board, wood, pvc with out. with out plastic, vulcanised natural rubber.
A	105°C	Cotton, silk & paper when impregnated 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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B	130°c	Mica, glass fibre, asbestos. etc.
F	155°c	Mica, glass fibre, ~~asbestos~~ as well as other material not necessarily inorganic, which by experiance or accepted test can be shown to be capable operation at 155°c.
H	180°c	Material such silicon elastomer & combination of material such mica, glass fibre etc.
C	above 180°c	mica, porcelin, glass & quartz with out an inorganic binder

Hygroscopicity :→ Many insulator come in contact with atmosphere either during manufacture or operation or both. the contact of insulation with atmospher is often so complete that even the less chemically agressive atmosphere

Moisture due to high humidity atmosphere can affect ~~insulation~~ insulator in two ways :—

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

However there are insulating material like parattins, polythene, polytetra-fluro thylen (PTFE) which are non-hygroscopic.

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

vii) Asbestos & asbestos products.
viii) Glass.
ix) Natural & synthetic rubbers
x) Insulating resins & their products.
xi) Laminates, Adhesives, Enamels & varnishes.

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 tensile strength varies, depending on the kind of wood & is bet^n 700 & 1300 kg/cm^2 along the grain.

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

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

(c) Insulating Textiles :→

Textiles are woven from fibrous material like cotton, jute and hemp. Sometime 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 temperature & 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.

Impregnate → fill with certain quality

1) **Jute:** → 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:** →

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

a) **Impregnated paper dielectrics:**-

Amongst all fibrous material used as insulat[cut off] this class contributes the maximum. The techni[cut off] of impregnation is complicated. Oil used fo[cut off] this purpose are selected carefully depending on requirements.

Main features of impregnated paper insulation are: →

a) Good mechanical properties.
b) Good chemical stability.
c) Ability to withstand high temperatures.
d) Dielectric constant varying betn 2.25 &[cut off]
e) Comparatively less dielectric loss.

(f) Non inflammable.

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 400 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 thicknesses of varnished textiles vary between 0.08 mm to 0.25 mm. This material belongs to class A insulating material.

Outstanding features of varnished textiles are :-

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

Application of varnished or impregnated textile :→

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

Nonresinous Materials :→

Solid or semisolid insulation which are directly available in nature and are organic based fall under this class. These material 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 called are semi solid materials obtained by refining crude petroleum.

Special features of bitumens are :→

i) Highly soluble in mineral & synthetic
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 electronic engineering because of its outstanding property of being water resistant. It is nearly cheap bitumens find wide application is underground cable for the protection of lead & steel armorer against corrosion.

(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 wax

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

(b) Natural waxes :- As the name implies these waxes are available in nature. Natural wax after gathers from is often used, after processing, in the form of paraffin wax.

→ 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 ~~proper~~ ~~point~~ These waxes also used a se constituent of sealing compound.

Insulating Liquids :→

Insulating liquids apart from working as insulation, fulfil other important requirement like :-

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

b) They offer good dissipation media.

i) They are sometime require for 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) flourinated 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 & alkalies.

iii) Stronger than compression than tension.

iv) Excellent dielectric properties.

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v) Weak in impact strength.

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

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Application of ceramics :-

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

a) Porcelin Insulator (T.f bushing, L.f, bushing
b) line insulator pin,
c) ~~other ceramic material~~

Mica & Mica Products :→

Mica is an inorganic Material. It is one of the best natural insulating material available. In spite of the tremendous progre[ss] made in insulation technology this materi[al] & its products still find many application in the present day. It is one of the oldest insulation of outstanding performance. India fortunately 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) Phologopite Mica.

b) <u>muscovite mica</u> :- Chief sources of supply are India, Brazil & U.S.A but the best available in India. The basic chemical composition of muscovite mica is $KH_2 Al_3 (SiO_4)_3$.

<u>Some more properties of muscovite mica</u>:

i) Strong, ~~tong~~ tough, & less flexible.

ii) colourless, yellow, silver or green in colour.

iii) Insulating properties are very good.

<u>Application</u> :- It is generally used where electrical requirement are severe.

<u>Phlogopite mica</u> :→ Principle source of supply are Malagasy, U.S.A & Canada. The basic chemical composition is $KH(MgF)_8 \, Mg \, Al (SiO_4)_3$. It is also called magnesium mica.

Some Properties :—

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

ii) resistant to alkalies 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, toaster etc.

Asbestos & Asbestos Products :→

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

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 contain

about 14% moisture at room temperature.

Amphibole Asbestos:-

a) Principal sources & south africa & Alaska.

b) It does not lend itself to easy spinning because the fibre 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 such uses it is~~

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

Application of Glass :-

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

Natural and synthetic Rubbers :-

Natural rubber is obtained from the milky sap of special trees. It finds very limited application in engineering. The reason are that it is rigid when solid, sticky when warm and it get oxidised when exposed.

→ In common language rubber is a material which is stretchable to more than twice its original length without permanent deformation.

Insulating Gases :-

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

Simple gases	Hydrocarbon gases	Oxide gases	Electronegative gases
Air, Nitrogen, Hydrogen, Helium, etc.	Carbon dioxide, Sulphur dioxide	Methane, Ethane, Propane, etc.	Freon and Sulphur hexafluoride

→ 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:

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

→ Air acts as an insulation in many electrical application in addition to the solid or liquid insulating material provided. commonly examples are over head transmission line, condenser, 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 for both 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 characterised by cooling property which is superior to those of air & nitrogen.

:- 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 Permitivity :-

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 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 materi[al] as the dielectric to the capacitance when air is substituted for the material is called permitivity or dielectric constant of that material

Polarisation :→

It has already been stated that Polarisation of dielectric is analogouz to Magnetisation of Magnetic Material. If a slab of dielectric placed in an electro static field it will undergo Polarisation. polarisation is defined as the definite orientation of electro-static 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 electrones are able to shift to their extreme position. Electrone displacement in this type of polarisation is elastic in nature.

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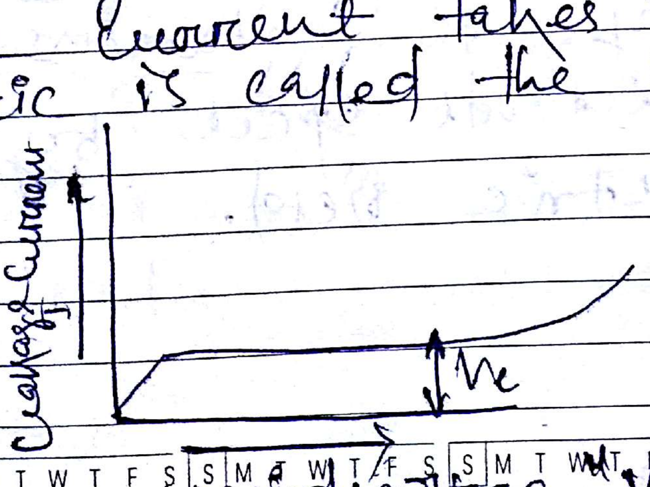
→ In the case of Polar dielectrics the orientation of the dipoles in the electric field is not a pure elastic displacement process. It involves overcoming of certain internal friction forces on which certain amount of energy is expended. This amount of energy is known as dielectric loss.

Electrical conductivity of Dielectrics and their Breakdown:→

Gaseous Dielectrics:→ The electrical conductivity of all gaseous dielectrics in 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 contaminates 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 depend upon presence of various contaminants or impurities.

→ A Breakdown in a contaminated liquid dielectric may occur due to the formation of conducting 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 electro thermal 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 following:

i) capacitor that use vacuum / air or other gases as dielectrics

ii) capacitor in which the dielectric is a mineral oil.

iii) Capacitor in which combination of solid and liquid dielectric such as paper, films of synthetic materials, glass, mica etc & mineral oil silicon 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 capacitor 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 by pass, 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 ~~permeability~~ ~~of air is almost~~ 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 $\mu_r = 1$.

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 Dimagnetic, paramagnetic & ferromagnetic materials depending upon ~~the~~ 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.

Dimagnetism:→ There are many materials in which the cancellation of magnetic field due to electrones rotating in opposite direction in the various orbit of the atom is total.

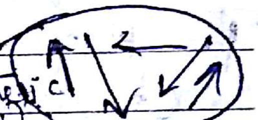
→ If an external magnetic field is applied to a diamagnetic material it induces a magnetization M in opposite direction to the applied field intensity, H. This means that the relative permeability μ_r of a dimagnetic material is negative.

→ This makes dimagnetism unimportant for electrical engineering applications &

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

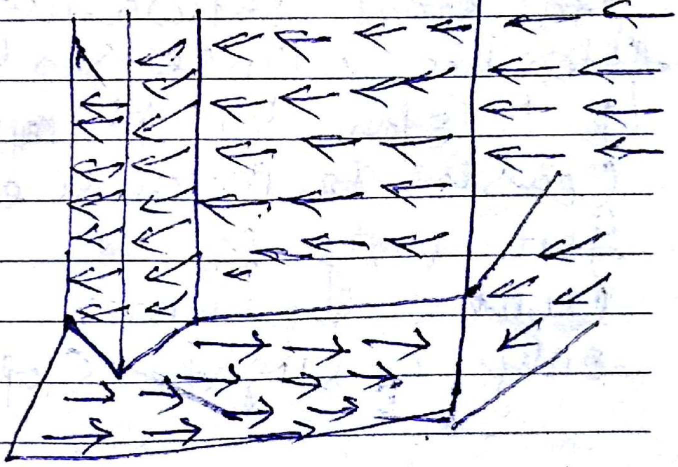
Paramagnetism:→

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



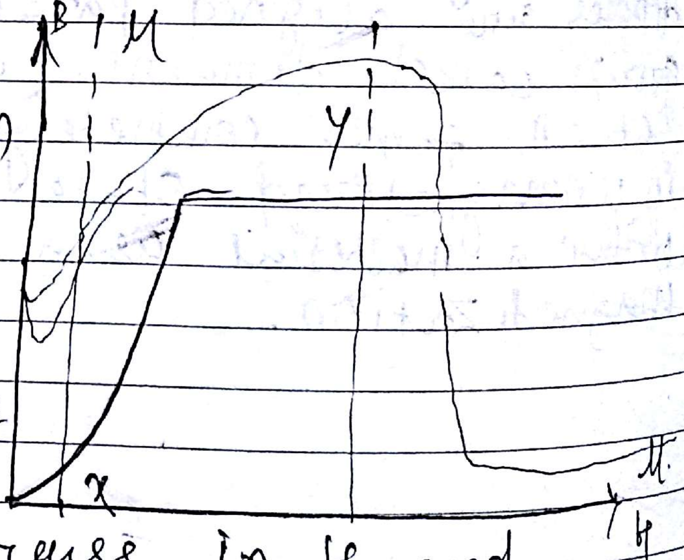
(Random orientation of the individual atomic dipole of a paramagnetic material)

ferromagnetism:- ferromagnetic materials are generally crystalline solids. The permanent atomic dipoles are aligned parallel to each other within groups called domains. Each domains 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, μ (= B/H i.e slope of the B-H curve of the material upto the point x is constant.



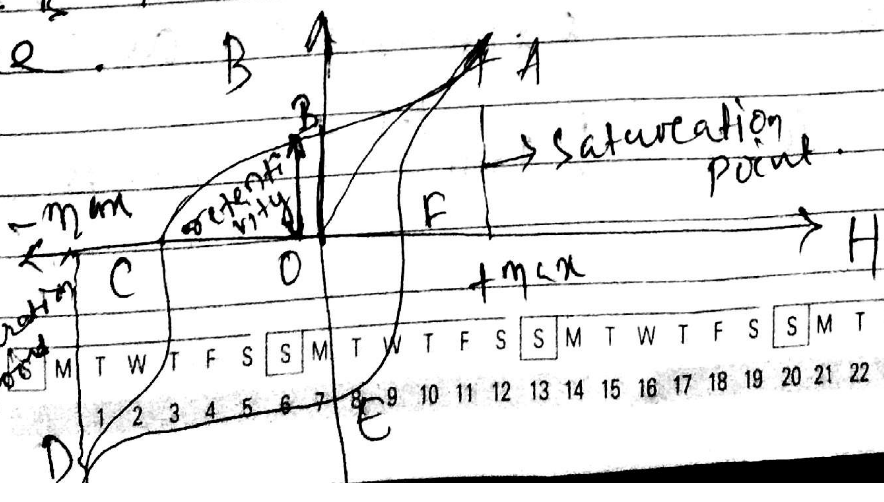
→ When the magnetization curve reaches the point y, the material is said to start saturating. After this, increases in B is slow till it almost ceases to increase even for very large increase in H, and curve becomes almost horizontal with only a slight slope upwards.

Hysteresis :→

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

→ ~~Upto this point~~ If 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 OC. This is called the remanent flux density or the residual magnetism.

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



H↑ B↓.

use → permanent magnet.

→ The results of which represented in figure shows that B always lags behind H. This property of B lagging behind H is characteristics 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 traces a loop ACDEFGA 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.

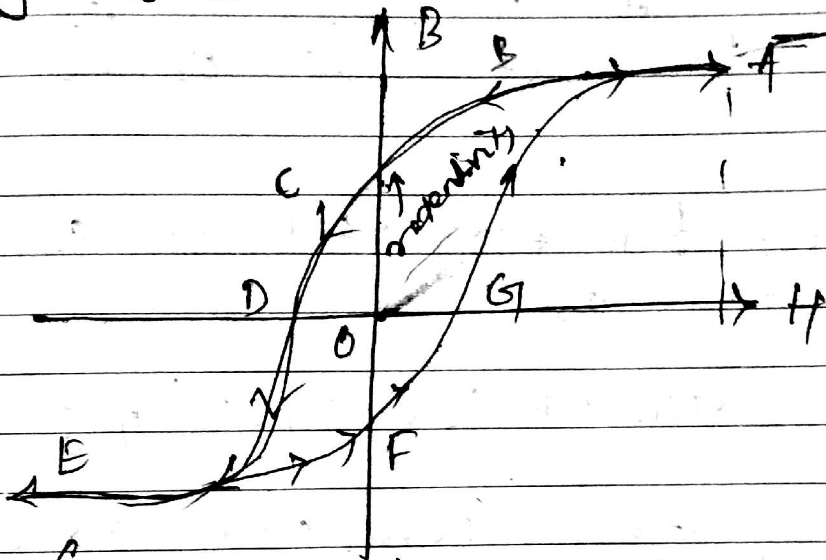
→ Hysteresis loss depends upon flux density and frequency of variation the flux and can be expressed as :-

Hysteresis loss :- $K B_m^{1.6} f V_e$ watts.

→ where K is constant whose value depends upon the core material, Bm = Maximum flux density.

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

~~Eddy currents:→~~



(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 of flux linkage & in accordance with faraday law of electro magnetic induction e.m.f's are induced in the material causing currents, called eddy currents, to flow in the material. These current cause loss of energy (I^2R 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 the heating up of the material.

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

Eddy current loss = $k \cdot B^2_m f^2 t^2 v_c$ watts

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

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CURIE POINT :→

There is the critical tempreture 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 ~~xxxx~~ 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 material are divided into two broad group :-

a) Soft magnetic material &
b) hard magnetic material.

~~The commonest soft magnetic~~

→ Narrow hysteresis loop and consequently small energy losses during cyclic magnetization are called soft magnetic material.

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

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

→ Such material are therefore used for making permanent magnets. Carbon 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 is 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%

→ 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 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, Supermalloy and Mumetal.

Permalloy :- This is used in manufacture of sensitive relay. The curie 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. It has initial permeability varying between 2500 to 8000 where as maximum permeability reaches as high as 100,000.

Supermalloy :→ It consist of iron & nickel alloyed with copper and molybdenum. This alloy is distinguished by its high initial permeability upto 100,000.

Mumetal :- It consist of iron and nickel alloyed with copper and chromium. It is used for manufacturing instrument transformer and miniature transformer (used in communication circuitries). It is heat treated upto 1100°c & having a curie temperature of 130°c. Its initial permeability is 20,000 & maximum pereabiuty is 110,000.

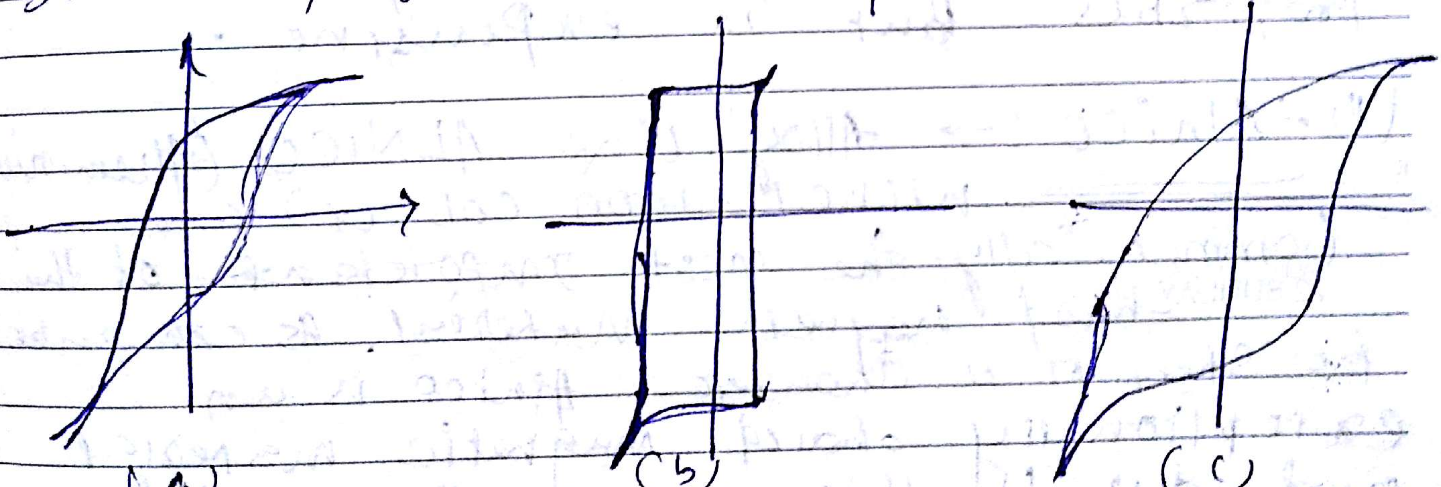
Soft ferrites :→ Ceramic magnets, also called ferromagnetic ceramic and ferrites, are made of an iron oxide, Fe_2O_3, with one or more divalent oxide such as NiO, MnO or ZnO. These magnets have a square hysteresis loop & high resistance to demagnetization & are valued for magnet for computing machine.

where a high resonance is desired.

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

Hard Magnetic Material:-

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



(a) (b) (c)

a) Soft magnetic material such as silicon steel.
b) Soft magnetic Material such as Permalloy.
c) 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 (Aluminium-nickel-iron-cobalt) are commercially the most important of the hard magnetic material. As compare to steel it is cheaper. Alnico is an exceptionally hard magnetic material and due to this reason now-a-days permanent magnet are most commonly made of Alnico.

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

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

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