CONDUCTING MATERIAL
1.1-1.11

INTRODUCTION: -

Materials which are used commercially for conducting electricity can be classed as conducting materials and materials which are used for preventing the flow of electricity can be classed as non-conducting or insulating materials.

Conducting materials have very low values of resistivity as compared to insulating material. To determine the extent to which a material has conducting or insulating property, we should know the value of its resistivity. Conducting materials can further be subdivided into low resistivity and high re-
resistivity materials.

Resistivity and factors affecting resistivity:

Resistivity: The reader already knows Ohm's law which can be written as V =IR, where, V is the value of the voltage between the terminals of a current carrying conductor, I is the current flowing through the conductor and R is the resistance of the conductor. The resistance R of any given material is directly proportional to its length 'l and inversely proportional to its cross-sectional area ‘a'

Thus, $R \propto \frac{l}{a}$ or $R = \rho \frac{l}{a}$ ohm, ...(2.1)

Where, ‘ρ’ is the coefficient of proportionality is called the resistivity or specific resistance of the material. In expression (2.1),

R = resistance of the material in ohm

r = resistivity of the material in ohm-m

a = area of cross=section of the material in sq-m

l = length of the material in meters.

Effect of Temperature on Resistivity: The most important factor which affects the value of resistivity is the temperature The resistance of most of the conducting material increases with temperature. The change in resistance of a material per ohm per degree change in temperature is called the "temperature coefficient of resistance of that material.

$R_t = R_0\,(1 + \propto t)$ ....(2.2)

Where, R_t and R_0 are respectively the resistances of the conductor at t degree and zero degree centigrade and $\propto$ the temperature coefficient of resistance.

If the resistance of the same material at any other temperature t_1 degree centigrade be R_{t1} then according to expression (2.2):

$$R_{t1} = R_0\,(1{+}\propto t_1\,)$$

Dividing expression (2.3) by expression (2.4) we ger,

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

(Adding and subtracting α t in numerator)

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

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

$$R_{t1} = R_t 1+\left[\frac{\alpha}{1+\alpha\, t}\,(\,t_1-\,t)\right] \qquad ....(2.4)$$

This means that the resistance at any temperature t_1 degrees can be calculated if the resistance at t degrees is known.

The resistance of a conductor changes with temperature according to the law Expression (2.4) is very important. It enables the designer of electrical equipment to determine by calculation the 12 R losses in the windings of equipment like motors and transformers. For this, he must know the resistance of the winding at the operating temperature. Assuming that the operating temperature of a transformer winding is 65 degrees centigrade above the ambient temperature (say of 3) degrees centigrade, then = 30 degrees C and = 95 degrees C. The value of resistance R, at ambient temperature (Let at 30 degrees C) is generally known to the designer. He can find from data books the value of the temperature coefficient and then calculate the resistance R. At the operating temperature (i.e., at 95 degrees C) by applying expression (2.4)-The relationship between temperature coefficient of resistance with change in temperature can also be found out by following ways. Let us assume that R. R, and R be the resistance of a conductor at 12 respectively then,

$$R_2 = R_1[1+\alpha_1\,(\,t_2-\,t_1)] \qquad ....(2.5)$$

$$R_3 = R_1[1+\alpha_1\,(\,t_3-\,t_1)] \qquad .....(2.6)$$

$$= R_1[1+\alpha_1\,(\,t_3-\,t_1)] \qquad ......(2.7)$$

Or,

$$\frac{R_3}{R_2} = [1+\alpha_2\,(\,t_3-\,t_2)] \qquad ......(2.8)$$

Dividing equation (2.6) by (2.5), we get,

$$\frac{R_3}{R_2} = \frac{[1+\alpha_1\,(\,t_3-\,t_1)]}{[1+\alpha_1\,(\,t_2-\,t_1)]}$$

$$= \frac{1 + \alpha_1\,(t_2 - t_1) + \alpha_1\,(t_3 - t_1) - \alpha_1\,(t_2 - t_1)}{1 + \alpha_1\,(t_2 - t_1)}$$

$$= 1 + \frac{\alpha_1\,(t_3 - t_2)}{1 + \alpha_1\,(t_2 - t_1)}$$

$$= 1 + \frac{\alpha_1}{1+\alpha_1\,(t_2 - t_1)} \times (t_3 - t_2) \qquad .....(2.9)$$

Comparing equation (2.8) and (2.9) we get,

$$= 1 + \alpha_2\,(t_3 - t_2) = 1 + \frac{\alpha_1}{1+\alpha_1\,(t_2 - t_1)} \times (t_3 - t_2)$$

Or $\alpha_2 = \frac{\alpha_1}{1+\alpha_1\,(t_2 - t_1)}$

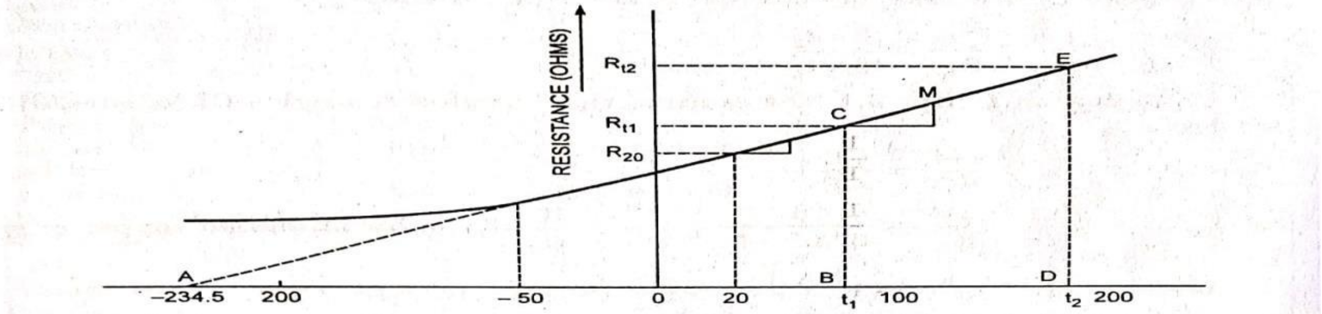
Or $\alpha_2 = \frac{\alpha_1}{\frac{1}{\alpha_1}\,(t_2 - t_1)}$

The test engineer can determine the actual temperature rise of the winding in this way: The resistance of the winding R_t, when the machine is not connected to the supply and when its winding is at an ambient temperature of t degrees, is measured. Then the equation is loaded under normal operating conditions for a sufficiently long time. Then its hot resistance R is measured immediately after switching off the supply. By knowing the value of a for the winding material, the temperature rise (4-t) can be calculated by applying expression (2.4).

It is important to note that the temperature coefficient of resistance, a is not constant. For understanding this let us rewrite expression (2.2) thus:

R = R, (1 + at) or R = R, + Ro at. (2.10)

This can be expressed graphically as in figure 2.1. This figure is drawn for annealed copper in which case resistance becomes zero at - 234.5°C (This value has been arrived at by extrapolating the graph; but in actual fact the graph tends to deviate from straight line at about-50°C as shown in figure 2.1). It is seen that the change in resistance with change in temperature is constant but since the graph does not pass through the origin the resistance is not directly proportional to the temperature. This is in fact also obvious from expression (2.5).



The Variation of Resistance with Temperature for Annealed Copper
Fig. 2.1.

Since the temperature coefficient has been defined as the change in resistance per ohm per degree change in temperature, it means that:

at $20°C$, $\alpha_{20} = \frac{\Delta R}{R_{20}}$;

at $0°C$, $\alpha_0 = \frac{\Delta R}{R_0}$;

Where, ΔR= change on resistance for 1° change in temperature,

R_0= resistance at $0°C$,

R_{20}= resistance at $20°C$,

In general :

$$\alpha_t = \frac{\Delta R}{R_t}$$

Where, $R_t = resistance\ at\ t$°C

$\propto_t = temperature\ coefficient\ of\ resistance\ at\ t$°C

$Thus\ for\ temperature\ t_1\ and\ t_{2\,,}$ we have:

$$\alpha_{t1} = \frac{\Delta R}{R_{t1}} \qquad ....(2.11)$$

and

$$\alpha_{t2} = \frac{\Delta R}{R_{t2}} \qquad ....(2.12)$$

Consider the similar triangle ADE and ABC, we have:

$$\frac{DE}{BC} = \frac{AD}{AB} \quad OR \quad \frac{R_{t2}}{R_{t1}} = \frac{234.5 + t_2}{234.5 + t_1}$$

The equation is true for anealed copper only. In general the straighy line graph will meet the temperature axis at different point depending upon the material. Let the point of intersection in general be taken as β degree below zero degree C. We may rewrite ecpression (2.13) thus:

$$\frac{R_{t2}}{R_{t1}} = \frac{\beta + t_2}{\beta + t_1}$$

Consider, in figure 2.1, the similar right angled triangles CLM and ABC, we have:

$$\frac{LM}{BC} = \frac{CL}{AB}$$

Or $$\frac{\Delta R}{R_{t1}} = \frac{1}{234.5 + t_1}$$ (True for annealed copper only)

We already knoe thet $\frac{\Delta R}{R_{t1}} = \alpha_{t1}$ (See expression 2.11)

Therefore, $$\alpha_{t1} = \frac{1}{234.5 + t1} \qquad ...(2.15)$$

Expression (2.15) is true for annealed copper only. In ganeral for any material :

$$\alpha_t = \frac{1}{\beta + t1}$$

If β is known, the temperature coefficient at any temperature can be found for any particular material.

Table 2.1 gives comparative study of the value of resistivity, temperature coefficient, density and melting point of different materials. Depending up on the application any of these materials may be selected.

Table. 2.1. Values of resistivity, temperature coefficient, density and melting point for different materials.

Material	Resistivity (ohm-m) at 20°C × 10^{-8}*	Temperature coefficient per degree C at 20°C × 10^{-4}*	Density	Melting point (degrees C)
Aluminium (cast soft)	2.8	35	2.68	655
Aluminium (hard drawn)	2.9	35	2.71	630
Carbon	400 to 1200	− 12 to − 60	1.9 to 2.3	3450
Copper (annealed)	1.72	39	8.89	1084
Copper (hard drawn)	1.77	39	8.89	1084
Iron (cast)	75 to 98	–	7.80	1500 to 1530
Lead	21	41	11.40	327
Nickel (commercial)	10.5	40	8.85	1450
Silver	1.60	40	10.50	960
Tin	11.50	46	7.30	232
Tungsten	5.50	50	18.80	3300
Silicon steel	50 to 60	–	7.70	–
Carbon steel (high carbon)	15 to 45	2 to 40	–	–
Carbon steel (up to 0.4 % carbon)	10 to 14	40 to 50	7.80	1350
Nichrome	100	4.4	8.15	1538
Brass	7	15 to 20	8.40 to 8.70	–
Manganin	48	0.5	8.40	102
Constantan	52	0.25 to 0.5	8.90	–

* 10^{-8} and 10^{-4} are factors by which the values in the corresponding columns are to be multiplied.

Example 2.1. A coil of a relay is made of copper wire. At a temperature of 20°C, the resistance of the coil is 400 ohms. Calculate the resistance of the coil at a temperature of 80°C. Temperature coefficient of copper is 0.0038 ohm per degree C at 0°C.

Solution : We know the relation :

$$R_{t_1} = R_t \left[1 + \frac{\alpha}{1+\alpha t}(t_1 - t)\right] \qquad \text{(from expression 2.4)}$$

Given, R_{20} = 400 ohms, α = 0.0038 ohm per degree C at zero degree C. It is required to find R_{80}.

Here, $R_{t_1} = R_{80}$, $R_t = R_{20}$.

Putting the given data in the above expression we get,

$$R_{80} = R_{20}\left[1+\frac{\alpha}{1+\alpha\times 20}(80-20)\right]$$

$$= 400\left[1+\frac{0.0038\times 60}{1+0.0038\times 20}\right]$$

$$\therefore \quad R_{80} = 484 \text{ ohms.}$$

Example 2.2. Calculate the resistance of a wire at 50°C which is 300 m long and has an area of cross-section of 25 mm^2. The wire is made of aluminium. Resistivity of aluminium at 15°C is 2.78 ohm-m. Temperature coefficient of aluminium is 0.004 ohm/degree C at 0°C.

Solution : Given $l = 300$ m, $a = 25$ mm^2, ρ at 15°C = 2.78 ohm-m.

$$R_{15} = \rho_{15}\frac{1}{a} = 2.78 \times \frac{300}{25\times 10^{-6}} = 33.4 \times 10^6 \text{ ohms.}$$

$$= 33.4 \text{ M}\Omega$$

$$R_{50} = R_{15}\left[1+\frac{\alpha}{1+\alpha\times 15}(50-15)\right]$$

$$= 33.4\left(1+\frac{0.004\times 35}{1+0.004\times 15}\right)$$

or

$$R_{50} = 33.4\ (1 + 0.132) = 38 \text{ M}\Omega$$

Example 2.3. A coil is made of copper-wire. At 15°C the resistance of the coil is 250 ohms. What will be the temperature of the same coil if its resistance is 300 ohms ?

Solution : Let R_{tx} be the resistance (= 300 ohm) at t_x degree C

Then,

$$R_{tx} = R_{15}\left[1+\frac{\alpha}{1+\alpha\times 15}(t_x-15)\right]$$

or

$$300 = 250\left[1+\frac{0.0038}{1+0.0038\times 15}(t_x-15)\right]$$

From which $t_x = 67$°C.

<u>Effect of alloying on resistivity:</u> Alloying is another factor which affects the resistivity of a material. By adding some impurities, a small percentage of some other material) to a metal its resistivity can be increased Alloys have higher resistivity than the pure base metal. At the same time, when a metal is alloyed, it also acquires properties like higher mechanical strength which are needed for certain applications. For example, when copper is alloyed with zinc, the alloyed material is called brass (60 % copper, 40 %zinc). By alloying copper with zinc its resistivity is increased i.e. conductivity is decreased by about 4 times (see table 2.1). But the tensile strength of brass is much more than that of copper and therefore may be used for making structural products such as rods, shafts, heavy plates, plug point, socket outlets, knife switches etc. where high strength and hardness are usually desirable.

Effect of mechanical stressing on resistivity: The resistivity of a material also changes under the influence of mechanical treatment The fabrication of conductor from the ingot to the final stage comprises initially hot working and finally cold-drawing Cold-working operation (stressing) distorts the crystal structure of the metal. This generally tends to harden the material increase its tensile strength and increase slightly its resistivity (see table 2.1) The increase in tensile strength in very useful for many purposes such as overhead conductor. That is why many types of conductors are finally drawn in cold stage in which case they are identified as hard drawn Although mechanical stressing increases the resistivity i.e. decreases the conductivity, annealing (Heat treatment process) restores the electrical conductivity by establishing regularity in crystal structure.

Classification of conducting materials into low-resistivity and high resistivity materials:

Low resistivity material: - Low resistivity materials are used in house wiring, as conductors for power transmission and distribution, in the windings of transformer and machines like motors and generators. In fact, low resistivity materials are used in all such applications where power loss and voltage drop should be low. Copper and aluminium are examples of commercially acceptable low resistivity material. Silver has lower resistivity than copper but because of its prohibitive cost its use commercially as a conductor is not feasible.

A low resistivity material, besides possessing low value of resistivity should also possess the following additional properties for rent against each:

(a) Low temperature coefficient: This means that the change of resistance with change in temperature should be low. This is necessary to avoid variation in voltage drop and power loss with changes in temperature. For example, the resistance of transmission lines which are very long will increase when ex-posed to hot summer sun. This will cause increase in voltage drop and power loss in the transmission line. The windings of electrical machines and apparatus become hot when loaded. This causes temperature rises and if the conducting material of the winding has high temperature coefficient of resistance, the voltage drops and power loss in the winding will be high.

(b) Sufficient mechanical strength: The overhead line conductors used for transmission and distribution of electrical power are subject to stresses due to wind and their own weight. The conducting materials used for the windings of transformers, motors and generators develop mechanical forces when loaded which can become very large if a high current flows due to a short circuit Also, when the coils for the windings of such equipment are made on former the conducting material is subject to mechanical stresses. Therefore, to with stand the mechanical stress, developed in the above mentioned application the conducting material should possess sufficient mechanical strength.

c) Ductility: - Ductility is that property of a material which allows it to be drawn out into a wire. Conductors are required in different sizes and shapes In some applications round wire section is used, while in others rectangular wire section is used The conducting material should be ductile enough to enable itself being drawn into different sizes and shapes.

(d) Solderability: Conductors have often to be jointed. The joint should offer minimum contact resistance. A simple joint would be to twist the conductor with the material to which it is to be jointed. But this gives high contact resistance. Minimum contact resistance results if the joint is soldered A material do not tend themselves to proper soldering. So while selecting conducting material, this point should be kept in view

(e) Resistance to corrosion: The conducting material should be such the it is not corroded when used in out-door atmosphere. Note 1 The reader should not lead himself to believe that all conducting materials should possess all the above mentioned properties. Depending upon the applications an appropriate material should be chosen which may not have all the above properties but those which the particular applications called for.

High resistivity materials:- High resistivity materials are used for making resistance elements for heating devices, starters for electric motor resistance used in precision measuring instruments, loading resistances and rheostats and filaments for incandescent lamps, In fact, high resistivity materials are used in all such applications where a large value of resistance is required If low resistivity materials were used for such application the length of the wire would be too large which would increase to a large extent the of the equipment. A high resistivity material besides possessing high values of resistivity should also posses the following additional properties for reasons mentioned against each.

(a). **Low temperature coefficient:-** High resistivity material are often used as shunts in electrical measuring instruments in making wire-wound precision resistance and resistance boxes. For Such precision application an important requirement is that the material of the element should have negligible temperature coefficient of resistance as otherwise the accuracy of measurement will be reduced.

(b). **High melting point:-** In applications like loading rheostats and starters for electrical motors the material of the resistance element should be able to withstand high temperature for a long time without melting. The Consideration of the resistance" temperature coefficient in these cases is also important but comparatively high values than those mentioned in above are permissible.

The consideration of high melting point is important also for resistance material used in electrical heating devices like room heaters, furnace, etc.

(c). **No tendency for oxidation:-** Material used as high resistance elements in heating appliances should be able to withstand high temperature for a long time without oxidation. This is because of an oxide layer is formed on the heating element the amount of heat radiation will reduce.

(d). **Ductility:-** High resistance material are required in the shape of very thin wires in the case of precision wire - wound resistors and in the shape of thick wires in case of the elements used in ovens, heaters, starters, etc. High resistance materials to be used for such application should therefore be capable of being drawn in to wires of different sizes and further be capable of being coiled.

(d). **High mechanical strength:-** High resistivity materials to be used for applications where the wire must be very thin and required to have high tensile strength as otherwise they may break during the braw of the wire or during the assembly and subsequent operation.

Example 2.4 A heater element 18 made of nichrome wire having resistivity equal to 100 x 10 ohm metre. The diameter of the wire is 0.4 mm
(a) Calculate the length of the wire required to get a resistance of 40 ohms and 1000 watts
(b) Calculate also the length required if the material of the element was copper having same cross-sectional area. Assume resistivity of copper to be 1.732 x 10- ohm-metre.

Solution: (a) When the element material is nichrome
ρ = 100 x 10 ohm-m.
d = 0.4 x 10 mm
a=12.6 x 10m
R= 40 ohms

We know that:

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

Therefore, $$40 = 100 \times 10^{-8} \times \frac{l}{12.6 \times 10^{-8}}$$

$$l = 5\ metres$$

Or

(b) When the element material is copper ,

$$\rho = 1.72 \times 10^{-8}\ ohm - metre$$

$$a = 12.6 \times 10^{-8}\ m^2$$

R= 40 ohms.

Therefore, $$40 = 1.72 \times 10^{-8} \times \frac{l}{12.6 \times 10^{-8}}$$

$$l = 296\ metres$$

Low Resistivity Materials And Their Applications:-

Copper

Properties :

1. Pure copper is one of the best conductors of electricity and its conductivity is highly sensitive to impurities.
2. It is reddish-brown in colour.
3. It is malleable and ductile.
4. It can be welded at red heat.
5. It is highly resistant to corrosion.
6. Melting point is 1084 0C.
7. Specific gravity of copper is 8.9.
8. Electrical resistivity is 1.682 micro ohm cm.
9. Its tensile strength varies from 3 to 4.7 tonnes/cm^2.
10. It forms important alloys like bronze and gun-metal.

Uses : Wires, cables, windings of generators and transformers, overhead conductors, busbar etc.

Hard drawn (cold-drawn) copper conductor is mechanically strong with tensile strength of 40 Kg/mm^2. It is obtained by drawing cold copper bars into conductor length. It is used for overhead line conductors and busbars.

Annealed Copper (Soft Copper) Conductor. It is mechanically weak, tensile strength 20 Kg/mm^2, easily shaped into any form.

Low-resistivity Hard Copper. It is used in power cables, windings and coils as an insulated conductor. It has high flexibility and high conductivity.

➢ **Silver**

Pure silver has high electrical conductivity and corrosion resistance. It is used where high resistance is not required. In order to make it hard 15% of copper is added into it. To make it more hard for use in commutator segment of DC motors as alloy of a silver-copper containing 40% of copper is used. For brushes and collector ring motors silver graphite alloy containing a small percentage of graphite is used because it provides sliding lubrication.It is best known electrical conductor.

Properties

1. It is very costly.
2. It is not affected by weather changes.
3. It is highly ductile and malleable.
4. Its resistivity is 165 micro ohm cm.

Uses : Used in special contact, high rupturing capacity fuses, radio frequency conducting bodies, leads in valves and instruments.

➢ **Aluminium -**Aluminium is widely available in India and is used extensively in the field of electrical engineering. So far as electrical conductivity is connected, it is next best to copper. Its resistivity is 2.8×10^{-8}ohm-m. It can be drawn into the wires. Aluminium is soft metal but when alloyed with some other material like magnesium, Silicon or iron it requires higher mechanical strength and can be used for overhead transmission lines.

Aluminium is quite extensively used for flexible wires overhead transmission lines, bus-bars, squirrel cage induction motor rotor bars and in many other applications
Properties:
1. Pure aluminium has silvery colour and lustre. It offers high resistance to corrosion. Its electrical conductivity is next to that of copper.
2. It is ductile and malleable.
3. Its electrical resistivity is 2.669 micro ohms cm at 20^{0}C.
4. It is good conductor of heat and electricity.
5. Its specific gravity is 2.7.
6. Its melting point is 658^{0}C.
7. It forms useful alloys with iron, copper, zinc and other metals.
8. It cannot be soldered or welded easily.
Uses : Overhead transmission line conductor, busbars, ACSR conductors. Well suited for cold climate.

➢ **Steel**.

Steel contains iron with a small percentage of carbon added to it. Iron itself is not strong but when carbon is added to it, it assumes very good mechanical properties. The tensile strength of steel is higher than that of iron. The resistivity of steel is 8-9 times higher than that of copper. Hence, steel is not generally used as conductor material. Galvanised steel wires are used as overhead telephone wires and as earth wires. Aluminium conductors are steel-reinforced to increase their tensile strength.

- **Gold :-** Gold is the best known electrical conduction. It is found of all-over the world but not a sufficient to make it economical. Gold is generally found veins among rocks and ores of other material. It is also found in the form of dust in the beds of rivers gold has a density of 19.3 times that of water at 20°C it melts at 1063°C and boils at 2100°C. It is malleable and ductile and can be easily beaten into translucent sheets as thin as 0.00001 mm. It is largely used as alloy to make coins and jewellery Its good corrosion resistance property makes its alloy very much useful as corrosive resistant brazing material.

Example- Calculate the diameter of copper wire of length for meters used as winding material in a temperature such that the resistance of the whole winding is 2 ohms. Calculate the diameter of the wire if aluminium is to be used for the above winding, resistance remaining the same.

Solution- We know:

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

Putting the values for copper wire we get :

$$2 = \frac{1.7 \times 10^{-8} \times 100}{a}$$

$$\therefore \quad \alpha = \frac{1.7 \times 10-8 \times 100}{a} = 0.85 \text{ sq-mm.}$$

Area, $a = \frac{\pi}{4} \times d^2$, where d is the diameter of the wire

$$\therefore \quad d = \sqrt{\frac{a \times 4}{\pi}} = \sqrt{\frac{0.85 \times 4}{3.14}} = 1.05 \text{ mm.}$$

For aluminium wire :

$$2 = \frac{2.8 \times 10^{-8} \times 100}{a}$$

$$a = \frac{2.8 \times 10^{-8} \times 100}{2} = 1.4 \text{ sq. mm.}$$

$$d = \sqrt{\frac{1.4 \times 4}{3.14}} = 1.34 \text{ mm.}$$

So the diameter of the aluminium wire is $\frac{1.34}{1.05}$

$= 1.28$ times that of copper wire.

Therefore, the space occupied by the aluminium winding will be more and hence the size of the transformer will be bigger.

<u>Standard Conductors</u>:- Standard conductor is made by twisting the wire (stands) together to form layers. Generally, Stranding is done in opposite directions for successive layers. This means if the wire of one layer is twisted in left-hand direction the next layer of wire will be twisted in the right hand direction and so on.

A standard stranding consists of 6 wines around 1 wire then 12 wires around the previous 6, then 18 wires around the 12, then 24 wires around the 18 and so on. The number of layers to be provided will depend on the number of wires to be provides Note that the central wire is not counted as a layer. Instead of a single wire, three or four standard wires may also be put in the centre and over them layers may be formed. It 3 standard wires are put in the Centre, 9 wires will be in the first layer than 15 wires in the second layer and so on. In each of the above case, the increase in the number of wires in each successive layer is 6.

Number of wire in centre	1 Wire	3 Wire	4 Wire
Number of wires in nth layer from centre	6n	3+6n	4+6n
Total number of wires in a standard conductor having n layer	$1 + 3n(1 + n)$	$3(1 + n)^2$	$(4 + 3n)(1 + n)$
Diameter over the nth layer in centimetre where d increases the	$(1 + 2n)d$	$(2.155 + 2n)d$	$(2.414 + 2n)d$

diameter of ach wire in centimetres			

Bundle Conductors:- "The adoption of bundled conductors in extra high tension power transmission enables standard conduction to be employed and gives an increased current carrying capacity compared with a single conductor of equivalent the voltage stress at the Conductor surface is reduced by using bundled Conductor corona loss is smaller and the time is less enable to Cause Radio interference.

Low Resistivity copper alloys :- We have noticed earlier that copper becomes mechanically hand when it is drawn. however, hardening of copper can also be done by alloying with other materials.

Brass :- When copper alloyed with tin (60%. Coppers & 40% of zinc) it is called Brass, Brass has high tensile strength but has lower conductivity than copper. It can be easily shaped by pressing and it lends itself to deep drawing.

Bronze :- Copper when alloyed with tin (8% to 16%) and a very small percentage of a third element like Cadmium, Beryllium, Phosphorus, Silicon, etc. is called Bronze. Bronzes are given their name based on the element which is added to copper and tin to form the alloy for example, when the third element is phosphorus, the alloy is called phosphor bronze. If the third element is silicon or cadmium, the alloy is called Silicon bronze or cadmium bronze, respectively. All bronze possess high mechanical strength as compared to copper but have lower conductivity. This is more corrosion resistance than zinc, So bronzes are more free from corrosion than brasses. Cadmium Bronze is use for contacting conductor and commentator segments. Beryllium bronze whose mechanical strength is higher than cadmium bronze which is used for making current carrying springs, sliding contacts and knife switch blades, etc.

Beryllium Copper alloy:- The copper alloy containing beryllium is also called Bronze. It has high conductivity and mechanical strength. Its hardening and elasticity property can be changed by giving appropriate heat treatment. It is used for making current carrying spring, brush holders, bellows, coil spring, sliding contacts and knife switch blades.

High Resistivity springs Materials and Their Applications :-

Common example of high resistivity materials are Manganine, Constantan, nichrome, Tungsten etc. Depending upon the application one of the specific above mentioned high resistivity materials is chosen to meet the specific requirements of the given application. For example- materials used in making wire wound precision resistance and shunts for measuring instruments, resistance boxes, coils for precision electrical measuring instruments and the like should have negligible temperature Coefficient of resistance and should be draw able.

Tungsten

Properties :

1. It is grayish in colour when in metallic form.
2. It has a very high melting point (3300^0C)
3. It is a very hard metal and does not become brittle at high temperature.
4. It can be drawn into very thin wires for making filaments.
5. Its resistivity is about twice that of aluminium.
6. In its thinnest form, it has very high tensile strength.
7. It oxidizes very quickly in the presence of oxygen even at a temperature of a few hundred degrees centigrade.
8. In the atmosphere of an inert gas like nitrogen or argon, or in vacuum, it will reliably work up to 2000^0C.

Uses : It is used as filaments of electric lamps and as a heater in electron tubes. It is also used in thermionic valves, radars. Grids of electronic valves, sparking and contact points.

➢ **Carbon**.

Carbon is mostly available as graphite which contains about 90% of carbon. Amorphous carbon is found in the form of coal, coke, charcoal, petroleum, etc. Electrical carbon is obtained by grinding the raw carbon materials, mixing with binding agents, moulding and baking it.

Properties :

1. Carbon has very high resistivity (about 4600 micro ohm cm).
2. It has negative temperature coefficient of resistance.
3. It has a pressure-sensitive reistance material and has low surface friction.
4. The current density is 55 to 65 A/cm^2.
5. This oxidizes at about 300^0C and is very weak.
6. It has very good abrasive resistance.
7. It withstands arcing and maintains its properties at high temperature.

➢ **Platinum**

Properties :

1. It is a grayish-white metal.
2. It is non-corroding.
3. It is resistant to most chemicals.
4. It can be drawn into thin wires and strips.
5. Its melting point is 1775^0C.
6. Its resistivity is 10.5 micro ohm cm.
7. It is not oxidized even at high temperature.

Applications:

1. It is used as heating element in laboratory ovens and furnaces.
2. It is used as electrical contact material and as a material for grids in specialpurpose vacuum tubes.
3. Platinum-rhodium thermocouple is used for measurement of temperatures up to 1600^0C.

➢ **Mercury**

Properties:

1. It is good conductor of heat and electricity.
2. It is a heavy silver-white metal.
3. It is the only metal which is liquid at room temperature.
4. Its electrical resistivity is 95.8 micro hom cm.
5. Oxidation takes place if heated beyond 300$_0$C in contact with air or oxygen.
6. It expands and contracts in regular degrees when temperature changes.

Uses : Mercury vapour lamps, mercury arc rectifiers, gas filled tubes; for making and breaking contacts; used in valves, tubes, liquid switch.

Super Conductivity:- There are some metals and mechanical compounds whose resistivity becomes zero when their temperature is brought near 0° Kelvin (-273°C). At this stage such metals or compounds are said to have attained superconductivity. For example - Mercury becomes super conducting at approximately 4.5° Kelvin (268.5°C). Super conductivity was discovered by Heike Kamerlingh Onnes at the University of Leiden in the Netherlands in 1911.

There are two types of superconductors commonly known type I and Type II superconductors. Type I Superconductors are they have soft superconductors. They are usually pure specimens of some elements i.e, metals they have very little use in technical applications. Whereas Type II super conductors are hard super conductors, they are usually alloys of metals with high value of resistivity in normal state. These are very useful as compared to type I super conductors.

Superconducting Materials:- Many metals and compounds have Superconducting property at very low temperatures. Super conductivity has been observed to occur in poorer conductors such as tin, lead and tantalum rather than in better conductors such as gold silver and copper.

It has been found that super conductors may not only be pure metal but various alloys and chemical compounds as well. At present about 30 superconductor metals and more than 6oo superconductor alloys are already known. The highest temperature at which until now, super conductivity has been observed to occurred is 20°k (-253°c) for a compound consisting of Niobium, Aluminium and Germanium.

Application of Superconductor Materials-

Electrical Machines:- Efforts are being made at present to develop electrical machines and transformers utilizing super conductivity. Calculations show that if we could use super conductors as conducting materials in addition to super conducting magnets which are already being produced. It is possible to manufacture electrical generators and transformers in exceptionally small size having an efficiency as high as 99.99%

Power Cables:- Super conducting material it used for power cables will enable transmission of power over very long distances using a diameter of a few centimeters without any significant power loss or drop in voltage.

Electromagnets:- Superconducting solenoids which do not produce any heat during operations have been produced. However it must be noted that superconductivity can be destroyed it the magnetic field exceeds a critical value. It has been possible to design electromagnet using superconductivity for use in laboratories and for low temperature devices like the maser.

Future Prospects:- It must be realized that the above applications require the conductor to be maintained at temperature very close to 0°k. This may often mean that the whole equipment associated with the conductor has to be kept at near 0ºk. This is a great challenge facing the scientists today. Indeed a new technology known as Cryogenics has been developed to tackle this problem

Presently Helium is used to achieve low temperature required for super conductivity. Helium being expensive gas efforts are being made to develop compounds which exhibit superconductivity at temperatures possible to be obtained by the more easily available and cheaper than Hydrogen gas.

Semiconducting materials

Introduction

"A semiconductor material is one whose conductivity lies between that of a conductor and an insulator." The two most commonly used semiconductor materials are germanium and silicon.

1.3 Conductor, Insulators and Semiconductors

Any solid is formed by bonding between atoms. Inter-atomic bonds are of three main types:

The first bond is the ***metallic bond***. In this type, the atoms of the elements which have 1, 2 or 3 valence electrons, being loosely held, give up those electron to form an electron cloud in the space of the atoms and become positive ions. The material is held together by electrostatic force between positive ions and electron cloud. The elements having small number of valence electrons are formed by this type of bonding and become ductile and have good conduction of electricity. These elements are known as ***conductors***.

The second one is the ***ionic bond*** where the atoms of different elements transfer electrons from one to the other so that both have stable outermost orbits. For example, in sodium chloride, sodium atom gives out its one valence electron to chlorine atom and both become stable with 8 electrons in outermost orbits. At the same time, one becomes positive ion and the other negative ion. The electrostatic force between the two gives rise to the bonding. High hardness and low conductivity are typical properties of ionic bond. Therefore these materials are ***insulators***.

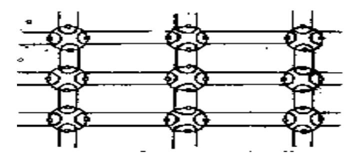


Fig 3.1

The third bond is called ***covalent bond***. In this bond, the atoms of the materials having 4 or more valence electrons share their electrons with neighbouring atoms as shown in Fig.3.1 The atoms of such materials behave as if they have full outer orbits.

This gives full strength to the material and low electrical conductivity because no electrons are free to move. Certain materials allow valence electrons to become free by thermal energy. These elements are known as ***semiconductors***.

An atom is identified by its atomic number which indicates the number of protons in the nucleus (or the number of electrons in the orbits). For example, an oxygen atom has 8 protons and 8 neutrons in the nucleus and 8 orbital electrons. Therefore, its atomic weight is 16 and atomic number is 8.

1.5 Electron Energy and Energy Band Theory

When each atom with its neighbouring atom shares electrons in order to fill its valence ring with 8 electrons, a covalent bond is formed. Figure-3.2 shows covalent bonding.

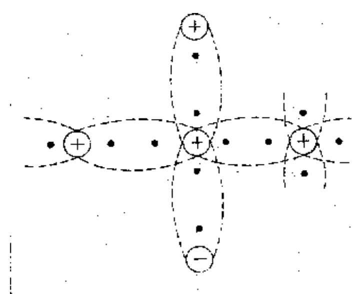


Figure -3.2 Set of covalent bond

When atoms enter into this bonding, each atom in effect has 8 valence electrons and this results in making such material a good insulator. Covalent bonding leads to the development of a poly crystal. In a poly crystal, several individual crystals are held

together imperfectly. The extra atoms are not properly locked in place. Due to impurities, there may be extra electrons which cannot lock into the covalent bond structure. Thus, a semiconductor is produced.

An impure material having three valence electrons is called trivalent bond, e.g. Gallium, Indium and Aluminium.

An impure material having five valence electrons is called trivalent bond,

e.g. Antimony, Arsenic, Phosphorous.

Excitation of Atoms

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

To move an electron further away from its nucleus requires additional energy. The additional energy can be obtained from any of the following sources: light, heat static electricity, magnetism, kinetic sources.

When the electron is in the higher energy level, the atom is said to be in an excited state. The quantum of energy, in electron volts, required to move an electron from one energy level to higher energy level varies from material to material.

When the required amount of light or heat energy is absorbed by a valence electron, it will leave the valence bond and move up to the ionization level. If it does so, it is released from the attraction forces of the nucleus. Then it is free to float between the atoms and to conduct electricity. An electron above ionization level is said to be in the conduction band and is called a free electron.

When the electron leaves the valency bond, the resulting atom is no longer neutral but has a positive charge and is called positive ion. The atom is said to be ionized.

The atom that has been ionized by the loss of an electron, does not remain so for a long time. Its positive charge will attract a nearby free electron which will give up its acquired energy. Thus, there is a constant interchange of electrons being given up and retrieved.

Energy Band Representation of lonization

In the silicon atom, K and L shells are full, but M shell contains only four electronics. According to the $2n^2$ formula, the M shell can contain 18 electronics, but the M shell in silicon is the valence shell and thus can have not more than 8 electronics.

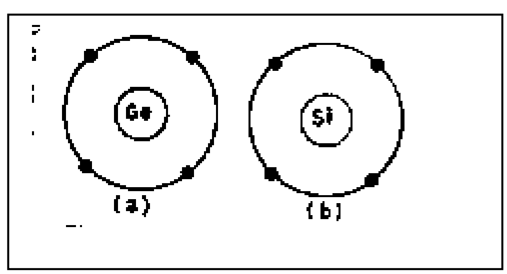


Figure -3.3 (a) simplified silicon and germanium atom

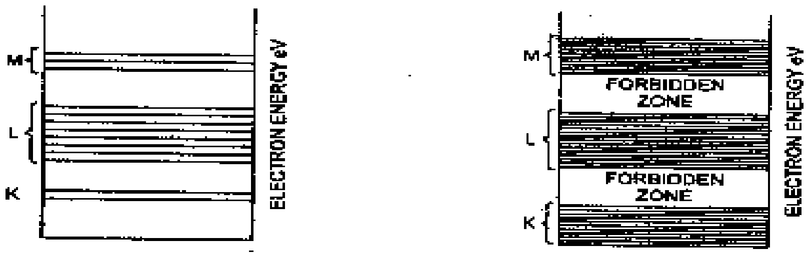


Figure -3.3 (b) Energy band representation of ionisation

In the germanium atom, the K, L and M shells are filled and the N shell is the valence shell containing 4electronics. Since only the valance electrons are important from the chemical and electrical point of view, both germanium and silicon atoms are shown in simplified from by representing only the outer most shell in Figs. 3.3 (a) and (b).

Simplified Si and Ge Atoms

The electrical characteristics of a semiconductor fall between those of a conductor and an insulator.

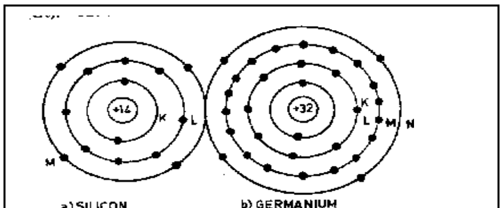


Fig- 3.4 Shell arrangement

A semiconductor has 4 electrons in its valence ring (outmost orbit). A good insulator has 8 electrons in its valence ring. The best conductor has one electron in the valence ring.

The two most widely used semiconductors are silicon (si) and germanium (Gi). Their atoms structure are shown in Figs. 3.4 (a) and (b).

N-type Material.

When a pentavalent impurity is added to an intrinsic material such as silicon or germanium, only four of its valence electrons lock into the covalent bond formation of atom structure. The fifth valence electron of the impurity atom is free to wander through the crystal.

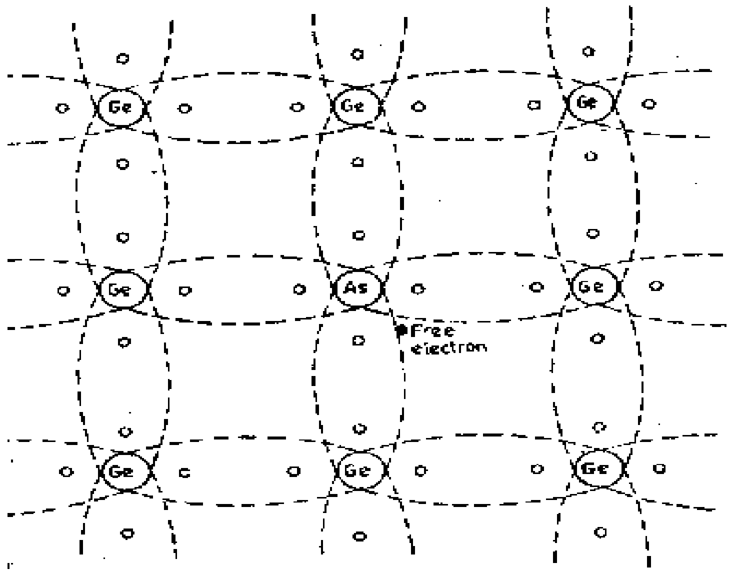


Fig- 3.5 Arsenic impurity atom provides a fifth electron

Figure 3.5 shows the addition of an atom of arsenic as an impurity. The impurity atom becomes ionized and has a positive charge when its fifth electron moves away. The positive impurity ion is not free but is firmly held in the crystal structure. The pentavalent atom donates an extra electron and is called a donor impurity. A material doped with a donor impurity has excess of electrons in its structure. It is called N-type material. The net charge of N-type material is still natural since the total number of electrons is equal to the total number of protons.

Arsenics impurity atom provides a fifth electron that cannot enter a covalent bond structure.

P-type Materials.

When a trivalent impurity is added to the intrinsic material, the two lock into a crystal structure. The impurity has three valence electrons. There is a hole in the covalent bond structure created by the lack of an electron. The hole represents an incomplete covalent bond and exhibits a positive charge. In order to complete the bond and from a stable 8-electron structure, a valence electron from a nearby atom gains sufficient energy to break loose from its bond and jumps into the hole due to its attraction. Therefore, this type of impurity is called an “acceptor”. The electrons available to fill the hole and complete the bond have been release by the nearby atom whose bonds have been broken and hole created. Thus, the process will continue creating a mobility of holes. The impurity atom becomes negatively ionized as accepts an electron. The germanium or silicon atom which releases one electron become positively ionized. The net charge of the material is still neutral. The total number of electrons is equal to the total number of protons.

<u>Semiconductors Commonly Used</u>

The following materials are commonly used as semiconductors:

(i) Boron
(ii) Carbon
(iii) Silicon
(iv) Germanium
(v) Phosphorus
(vi) Arsenic
(vii) Antinomy
(viii) Sulphur
(ix) Selenium
(x) Tellurium
(xi) Iodine

<u>Intrinsic Semiconductors.</u>

If a crystal (silicon or germanium) does not contain any impure atoms (contains only one type of atoms), it is called an intrinsic material. When an electron is freed from the atom of an intrinsic material, it breaks a covalent bond and leaves behind a vacancy (called a *hole*). The free electron and the hole form an electron-hole pair. The higher the temperature, the greater the number of free electrons and holds. When a voltage is applied to an intrinsic material, it acts as a conductor.

<u>Extrinsic Semiconductors.</u>

Pure silicon or germanium exhibits characteristics closer to that of an insulator than a semiconductor. In order to make a material conducting, a small quantity of impurity must be added to it. The addition of impurity makes pure germanium or silicon a conductor. The process of adding impurities is called “doping”.

The extent to which the impurity has been added is called the “doping level”. When a pentavalent group provides an extra electron to the semiconductor material, the atom of the material which donates the extra electron is called a “donor atom”

When a trivalent group is added to intrinsic materials such as silicon, one covalent bond is broken, that is, a hold is created. An electron from an adjacent atom can fill the hole which is now moved to another atom. The doping atom has now one surplus negative charge and has become a negative ion. A hole is the absence of an electron and hence has a positive charge. The doping element is an “accepted”, since it takes or accepts an electron.

Majority and Minority Carriers.

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

The small number of holes created by thermal generation ove in opposite direction. In N-type material, the number of free electrons is large. These electrons are called majority carriers. Holes are in small numbers and are called minority carriers.

In p-type material, the holes are majority carriers and electrons are minority carriers.

➢ Working and Application of Semiconductors

Semiconductor materials are used in :

(i) Rectifiers

(ii) Temperature-sensitive resistors

(iii) Photoconductive and photovoltaic cells

(iv) Varistors

(v) Hall effect generators

(vi) Strain gauges

(vii) Transistors

(viii) LDR and LCD

Some of them are discussed below

<u>Germanium and Silicon Rectifiers</u>. When a P-type material and an N-type material are joined together, they form a junction called P-N junction.

When an external voltage is applied across the two material, a flow of current results if the positive and negative terminals of the voltage source are connected respectively to the ends of the P and N material. The voltage applied this way is called “forward-biasing” the P-N junction. If the applied voltage is reversed, that is, the positive of the supply voltage is connected to N side and negative of the supply is connected to the P side, there is no flow of current. This is called “reverse biasing”. Thus the P-N junction offers high conductivity when forward biased and no conductivity when reverse biased. Thus, the semiconductor can be used as a rectifier. The modern P-N junction rectifiers use germanium or silicon material. Circuit diagram Fig. 3.6 a & b - below also illustrate the characteristics.

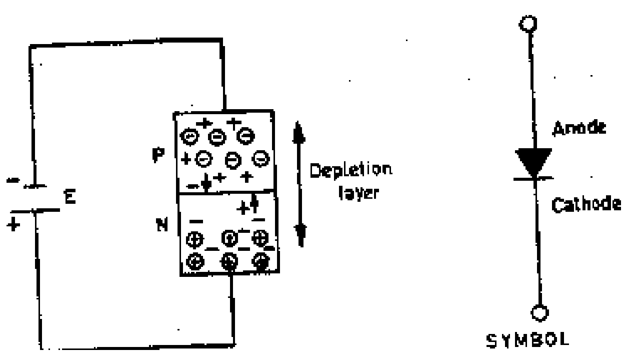


Fig-3.6 a The operation of PN junction under reverse bias

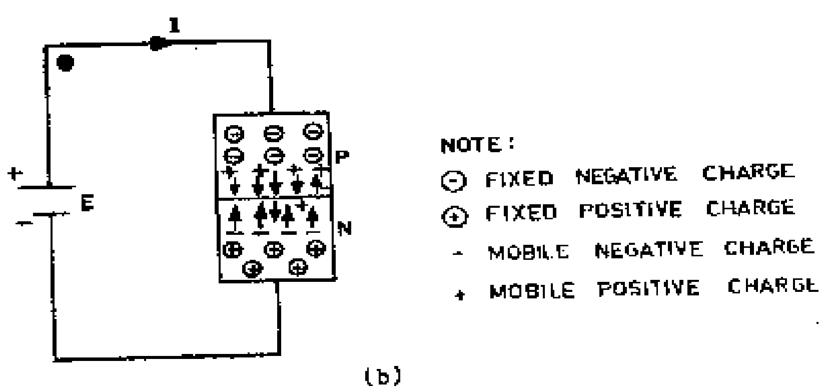


Fig- 3.6 b The operation of PN junction under forward bias

- **<u>Copper Oxide Rectifiers</u>**. The earliest semiconductor to be used was copper oxide. Its application was in copper oxide rectifier.

Copper oxide rectifier is a place of 99.98 % pure copper on which a film of fuprous oxide is produced by a special process. From one side of the plate, cuprous oxide is cleaned and electrode is soldered directly to the copper. The second electrode is soldered to cuprous oxide film. When a positive potential is applied to the oxide layer and negative to the copper, it corresponds to forward biasing of a P-N junction. By arranging the copper plate elements in stacks, rectifiers for use in many kinds of measuring instruments and circuits can be obtained. These rectifiers have low permissible current density. They are not used for power supply purposes.

To have a good contact with copper oxide, a lead plate is pressed against it. The two terminals of the rectifiers are the copper plate and lead plate. The oxide will be in between the plates as shown in figure- 3.7. This rectifier will allow the current to flow only from oxide to copper and will not allow flow from copper to oxide.

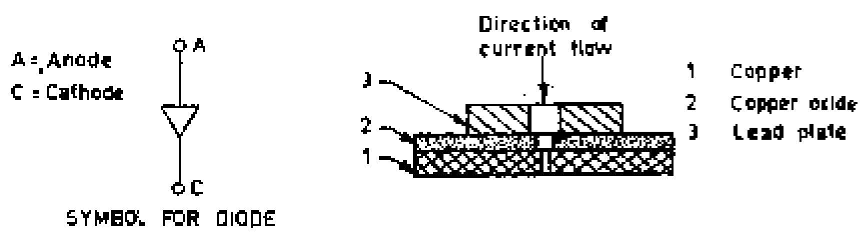


Fig- 3.7 **Copper oxide rectifier**

The voltage that may be applied to a single rectifier ranges between 4 and 8 V, so a number of units are connected in series for operating on high voltages. Similarly, parallel connected of the units, increases the current rating of the rectifiers, as the maximum current density in the forward direction is 0.1 to 0.15 A/cm^2 at an allowable voltage of 8 V.

The life of copper oxide rectifiers is 12 to 15 years and efficiency is 70 %.

Applications : These types of rectifiers are mostly used for meters, battery cell charging, X-ray works, measuring instruments, railway signaling, telecommunication systems, etc.

- **Selenium Rectifiers**.

In this type, a film of 0.5 mm. thickness is deposited on one side of the metallic back plate (iron or aluminium). By means of chemical treatment, a film of “blocking” or “barrier” layer is formed between selenium and counter electrodes.

The rectification is from back plate to selenium. The rectifier construction is as shown in figure-3.8.

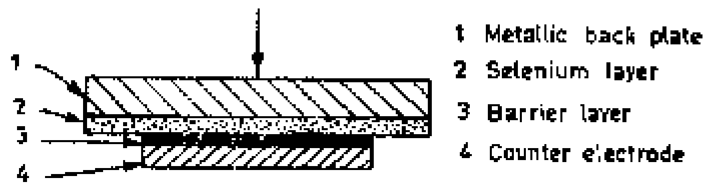


Fig-3.8 Selenium rectifier

A single unit can sustain 6 V. The normal current density is about 0.04 A per cm^2 for full wave rectification. The power efficiency is 50 to 75 %.

The units can be combined in series or in parallel, similar to that of copper oxide rectifiers to work at desired voltage or for the required current capacity.

Applications : This type of rectifiers are widely used for battery charging, telegraph and telephone circuits, control circuits, railway signaling, meters, electroplating and other works.

Such rectifiers are available in capacities of up to 50 to 100 KW.

- **Temperature-sensitive Elements (Thermistors)**

If the temperature of a semiconductor material is increased, that causes a decrease in its resistance. This property is used in temperature sensitive elements which are called as „thermistors‟.

The termistors are thermally sensitive material (resistors). They are made from oxides of certain metals such as copper, manganese, cobalt, iron and zinc.

Applications of thermistors: Thermistors find application in temperature measurements and control. They sense temperature variations and convert these variations into an electrical signal which is then used to control heating devices.

Thermistors are also used for measurement of radio frequency power, voltage regulation and time delay circuits.

- **Photoconductive Cells**

The resistance of semiconductor materials is low under light and increases in darkness. Phtoconductive cells can be used in applications which require the control of a certain function or event according to the colour or intensity of light.

Applications: They are used in burglar alarms, flame detectors and control for street lights.

- **Photovoltaic Cells**

Photovoltaic cells are devices that develop and emf when illuminated. They convert light energy directly into electrical energy.

Applications: The applications of photovoltaic cells are in photographic exposure meters, lighting control systems, automatic aperture control in cameral.

- **Varistors**

The resistance of semiconductors varies with the applied voltage. This property is used in devices called varistors.

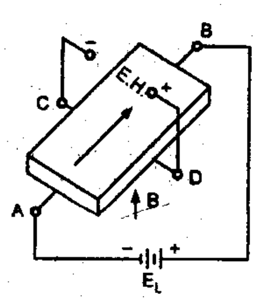
Applications. They are used in voltage stabilizers and for motor speed control.

- **Hall Effect Generators**

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

Consider the semiconductor bar shown in Fig.3.9, which has contacts on all four sides. If a voltage E_1 is applied across the two opposite sides A and B_2 a current will flow.

If the bar is placed perpendicular to magnetic field B as shown in the figure, an electrical potential E_H is generated between the other two contacts C and D. This voltage E_H is a direct measure of the magnetic field strength and can be detected with a simple voltameter.



Hall Effect Device

Fig- 3.9

Applications. The hall effect generators may be used to measure magnet is fields. It is capable of measuring magnetic field strengths that have a strength of 10^{-6} of the magnetic field of the earth.

- **Strain Gauges**

Semiconductors are sensitive to heat, voltage and magnetic field; they are also sensitive to mechanical forces. If a long thin rod of silicon is pulled from end to end, its resistance increases considerably because the mechanical force pulls each silicon atom slightly away from its adjacent atom. This increases the breadth of the forbidden energy gap, which increases the resistivity of the rod. Silicon and other semiconductors are used in strain gauges.

Applications: Strain gauges are used to find the small changes in length of solid substances or objects.

Insulating Materials

Introduction:

For safe and satisfactory operation of all electrical and electronics equipment insulator plays important role. Basically current carrying wires, surfaces need to be covered with insulating material. Let us see the structure of the material on the basis of energy band. In this type of material, the highest occupied energy band (Valence Band) is completely filled. The next higher band (Conduction Band) is quite empty.(Fig.1) The gap between these two bands is too large. When the electric field is applied across these materials, the electrons from valence band cannot reach the conduction band and conduction of electron stops. Such materials are known as insulators. Diamond is an example of this kind of material with a separation of nearly 6eV between valence band and conduction band.

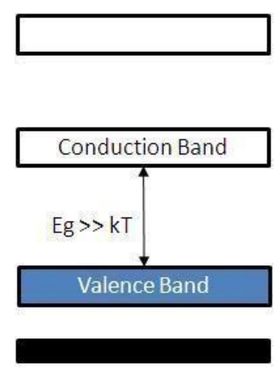


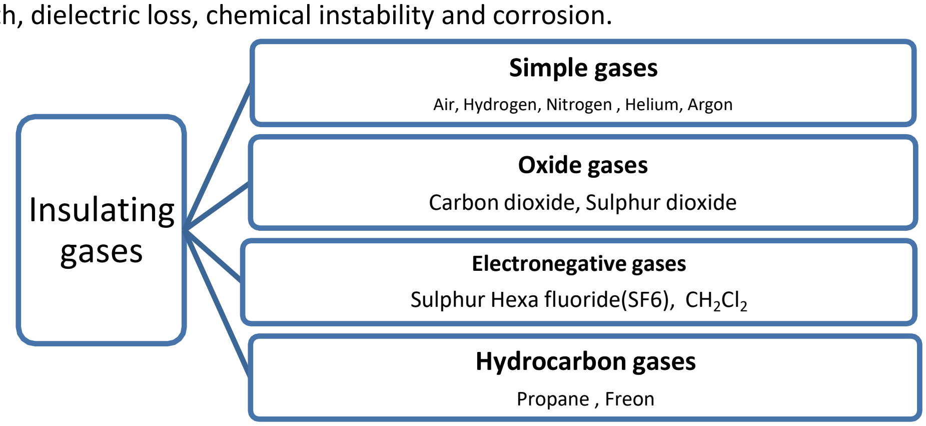
Figure 1. Energy band of INSULATOR

Insulating Materials for Electrical Engineering

The insulating materials used for various applications in electrical engineering are classified in three categories:

- Insulating gases
- Liquid insulating material
- Solid insulating material

1. ***Insulating Gases***: Many gases are used as the medium of heat transfer. All known gases are dielectric in pure form, but from electrical engineering point of view these are classified on the basis of different properties like dielectric strength, dielectric loss, chemical instability and corrosion.



2. **Liquid Insulating Material**: These materials are used for dielectric purpose to eliminate the air and other gases Insulating liquids are organic liquids used as coolant. These are categorised according to temperature range where they are used. It is used in transformers, circuit breaker, bushings, cables, capacitors etc. along with solid insulants to operate with an acceptable performance. An ideal insulating liquid material must have following properties:
    - High dielectric strength, impulse strength and volume resistivity.
    - Low dielectric dissipation factor.
    - High or low dielectric constant.(depending upon application)
    - High specific heat and thermal conductivity.
    - Excellent chemical stability and gas absorbing properties.
    - Low viscosity, density, volatility and solvent power and high flash point.
    - Good arc quenching properties.
    - Non-flammable and non toxic

Table 1 *Liquid Insulating Materials*

Type of Liquid	Temperature Range	Applications
Petroleum oils (Mineral oils)	*-50 to 110^{0}C*	All types
Askarels	*-50 to 110^{0}C*	Transformer, Capacitor, Switch gear
Silicon Liquids	*-90 to 220^{0}C*	Transformer,
Halogenated Hydro carbon	*-50 to 200^{0}C*	Electric equipment
Synthetic hydro carbon	*-50 to 110^{0}C*	Cables and Capacitors
Organic esters	*-50 to 110^{0}C*	Electronics equipments
Vegetable oil	*`-20 to 100^{0}C*	Limited application

General Properties of Insulating Material:

The suitability of an insulating material for a specific purpose use can be decided by knowing its different properties. So we have to know the exact requirement of the application and the required property hold by the insulating material. Based on uses in different applications following properties of materials are useful.

1. **Electrical Properties:** The insulating material used in electrical or electronics appliances, should be considered for following:
    - Insulation resistance
    - Dielectric constant or permittivity
    - Breakdown voltage or dielectric strength
    - Dielectric loss

1. 1 Insulation Resistance:

This is the ohmic resistance offered by an insulation coating, cover or material in an electric circuit which tends to produce a leakage current through the same with an impressed voltage across it.

Let us consider a cable of inner and outer radii r_1 and r_2, length l and resistivity of insulating material ρ. Considering a very thin layer of radial thickness *dr* at a radius *r*, the length through which the leakage current flows is *dr* and area of cross section provided to flow of current is $2\pi rl$.

Hence insulation resistance of the layer under consideration $= \frac{\rho dr}{2\pi rl}$

Insulation resistance of the cable can be determined by integrating above expression between the limits r_1 and r_2. Insulation resistance of the cable is given by,

$$R = \int_{r1}^{r2} \frac{\rho dr}{2\pi rl} = \frac{\rho}{2\pi l}\int_{r1}^{r2} \frac{dr}{r} = \frac{\rho}{2\pi l} log_e \frac{r_2}{r_1}$$

The equation states that, the resistance of the cable decreases with increase in length.

1. 2 Dielectric constant or Permittivity:

The permittivity of the insulating material varies with temperature and frequency in some cases. The materials like HCl, H_2O, CO, NH_3 have permittivity variation with change in temperature.

1. 3 Dielectric strength:

It is the maximum impressed voltage bearing capacity of insulator per unit thickness of material, up to which current does not flow through it. When current flows through the insulator is known as dielectric failure.

The dielectric strength of an insulating material decreases with the duration of time the voltage is applied, moisture, contamination, high temperature, heat ageing, mechanical stress etc. and decreases up to 10% of laboratory values.

1. 4 Dielectric loss:

Dielectric losses occur in all solid and liquid dielectric due to: a conduction current and hysteresis.

- The conduction current is due to imperfect insulating qualities of the dielectric and is calculated by the application of Ohm's law. It is in phase with the voltage and results in the power loss (I^2R) in the material, which is dissipated as heat.

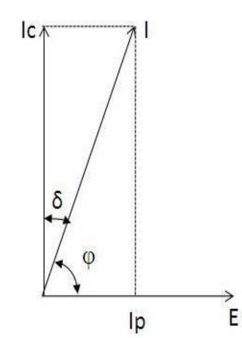


Figure 2. Plot of E against Ic

- Dielectric hysteresis is defined as the lagging of electric flux behind the electric force producing it so that under varying electric forces a dissipation of energy occurs. The energy loss due to above cause is called the dielectric hysteresis loss. The energy is dissipated as heat. This loss gives an indication of the amount of energy absorbed by the material, when subjected to AC fields.

2. Visual Properties:

An insulating material possessing two opposite properties: transparency and thermal insulation is suitable in case of reduction of energy consumption for heating and air conditioning and electrical energy savings. This is known as visual properties. Study of appearance, color and crystalline structure are the measures of this property. Glass, Aerogel hold the required visual properties. **Aerogel** is used in case of highly energy efficient windows.

3. Mechanical Properties:

Mechanical properties such as tensile strength, impact strength, toughness, hardness, elongation, flexibility, mechanical strength, abrasion resistance etc. are to be considered for choosing the insulating material.

3. 1. Mechanical Strength:

The insulating material should possess sufficient mechanical strength to respond mechanical stress. Mechanical strength is affected by following factors.

- Temperature rise: It badly affects the mechanical strength of the insulating material.
- Humidity: It is the climatic effect which affects also the mechanical strength.
- Porosity: An insulating material of high porosity will absorb more moisture and thereby affects the electrical properties as well as mechanical strength.

4. Thermal Properties:

Following thermal properties are considered for selecting insulating material of different applications.

4. 1. *Thermal stability*: The insulating material must be stable (no change in physical state) within the allowed temperatures. Certain materials like wax and plastic get soft at moderate temperatures. So the mechanical property of the material is affected. Hence the operating temperature of the material is to be noted before its use.

4. 2. *Melting point*: The insulating material should have melting point (temperature bearing capacity without being melt), above that of operating temperature.

4. 3. *Flash point*: This is an important property of insulating oils used in transformer. Flash point of a liquid insulator is that temperature at which the liquid begins to ignite.

4. 4. *Thermal conductivity*: In electrical appliances heat is generated during operation, which should be transferred to atmosphere, to maintain the operating temperature within the limit. Hence the insulators should have very low thermal conductivity

4. 5. *Thermal expansions*: Rapid and repeated load cycle on electrical appliances cause corresponding expansion and contraction of the insulators. In a result voids are created and affect the breakdown phenomenon. Thus two insulating material of different coefficient of thermal expansion should be wisely selected.

4. 6. *Heat Resistance*: The insulating material used must be able to withstand the heat produced due to continuous operation and remain stable during the operation. At the same time it should not damage the other desired properties.

5. **Chemical Properties:**

Certain chemical properties are also required to be considered for the insulating materials.

5. 1. *Chemical Resistance*: It is the ability of the insulating material to fight against corrosion in the presence of gases, water, acids and alkalis. For materials which are subjected to high voltage, high chemical resistance is also necessary.

5. 2. *Hygroscopity*: Many insulating materials are hygroscopic. Sometimes the insulation may come in direct contact with water. The porous materials are more hygroscopic than dense ones. Small amount of moisture absorbed by an insulating material affects its electrical properties drastically.

5. 3. *Moisture Permeability*: The tendency of an insulating material to pass moisture through them is known as moisture permeability. Moisture can penetrate through very small pores as the size of water molecule is very small. So this property is vital for selecting the protective coating, cable sheaths etc.

6. **Ageing:** Ageing is the long term effect of heat, chemical action and voltage application. These factors decide the natural life of insulators and hence of an electrical apparatus.

Insulating Gas: Properties and applications

Air: Air provides insulation between the over-head transmission lines. It is the best insulating material when voltages are not very high. It is also used in air capacitor, switches and various electrical equipments.

It is easily available, non-inflammable, non-explosive, small dielectric strength (nearly 3to 5 kV/m) and reliable at low voltage.

Hydrogen: It is commonly used for cooling purpose in electrical machine due to its lightness. Its high thermal conductivity helps to transmit heat from windings of high capacity alternator. Thus it reduces windage losses and increases efficiency.

Nitrogen: Nitrogen is used in place of air, to prevent oxidation due to its chemically inert property. It is generally used in transformers, gas pressure cable and capacitors.

Carbon Dioxide: Carbon dioxide is used in certain fixed type capacitor, and is used as a pre-impregnate for oil filled high voltage apparatus, such as cables and transformers. The relative permittivity of carbon oxide is 1.000985 at 0^0 C.

Sulphur Hexafluoride (SF_6): The electromagnetic gases have high dielectric strength compared to other traditional dielectric gases like nitrogen and air. The dielectric strength of SF_6 is 2.35 times more than air. The electronegative gases are non-inflammable and non-explosive. The most important gas under this category is sulphur Hexafluoride, while others are Freon gases.

SF_6 is mostly used in high voltage application and its use is most satisfactory in dielectric machines, like X-ray apparatus, Van de Graff generators, voltage stabilizers, high-voltage switch gears, gas lasers etc. SF_6 bears some special properties as follows:

- SF_6 is colourless, nontoxic and non-inflammable gas. It is the heaviest gas and has low solubility in water. The gas can be liquefied by compression. Its cooling characteristic is better than air and nitrogen.
- Under normal temperature conditions it is chemically inert and completely stable with high dielectric strength.
- This gas has very good electronegative property. Its relatively large molecules have a great affinity for free electrons, with which they combine making the gas-filled break much more resistant to dielectric breakdown.

Liquid Insulating Material: Properties and applications

Mineral oils: The operating temperature range of mineral oil is 50-110^{0}C. These hydrocarbon oils are used as insulating oils in transformers, circuit breakers, switch gears, capacitors etc.

In transformers, light fraction oil, such as transil oil is used to allow convection cooling. Its high flash point is 130^{0}C, so it is able to prevent fire hazard. Highly purified oil have a dielectric strength of 180 kv/mm and if the oil contains polar and ionizing material its dielectric loss increases.The dielectric constant is about 2.3 and therefore it is capable of dissolving only very few substances in it and produce the conducting ions. The TRANSIL oil undergoes oxidation, particularly in in the presence of catalysts such as copper, to form sludge and acids.

Light oils having Saybolt viscosity of 100 seconds at 40^0C, have been used under pressure in oil filled high voltage cables.

More viscous or tacky oils with Saybolt viscosity of 2000 seconds at 40^0C, are generally to impregnate the paper in solid type cable.

Askarels: These are non-inflammable, synthetic insulating liquids, used in temperature range of 50 – 110^0C. Chlorinated hydrocarbons are the most widely used among the askarels because of high dielectric strength, low dielectric constant (4 to 6) and small dielectric loss. They do not decompose under the influence of electric arc and have good thermal, chemical and electrical stability.

Chlorinated hydrocarbons as askarels are used as transformer fluids to reduce fire hazards. Chlorinated diphenyl, penta chloro diphenyl, trichloro diphenyl, hexa chloro diphenyl, trichloro benzene, etc., are the most widely used hydrocarbons or askarels. Askarels are generally used to impregnate a cellulose insulating material, such as paper or press board etc., for its high breakdown strength.

Silicon Fluids: It is used in the temperature range of 90-220^0C and it is clear, water like liquid. It is available in wide range of viscosity and stable in high temperature. They are non-corrosive to metal upto 200^0C and bear excellent dielectric properties in wide range of temperature. So it is used as coolants in radio pulse and aircraft transformers.

Fluorinated Liquids: These are non inflammable, chemically stable oils used in temperature range of 50-200^0C. They provide efficient heat transfer from the winding and magnetic circuits in comparison to hydrocarbon oils and used in small electric and radio devices, transformers etc. In presence of moisture electrical properties are deteriorated.

Synthetic Hydrocarbon oils: Polybutylene, Polypropylene is the example of synthetic hydrocarbon oils. They have similar dielectric strength; thermal stability and susceptibility to oxidation properties are similar as that of mineral oils. The operating temperature range is 50-110^0C. These are used in high pressure gas filled cables and dc voltage capacitors.

Organic Esters: These organic fluids are used in the temperature range of 50-110^{0}C. They have dielectric constant and very low dielectric losses. The dielectric constant ranges from 2 to 3.5. The higher range of 12.8 is obtained in tetra hydro-furyloxalate. These fluids are well suited for use in high frequency capacitors.

Vegetable Oils: These insulating liquids have temperature range of 20-100^{0}C. Drying oils are generally suitable in the formation of insulating varnishes, while non-drying oils are used as plasticisers in insulating resin compositions.

Varnish: It is the liquid form of resinous matter in oil or a volatile liquid. Hence by applying, it dries out by evaporation or chemical action to form hard, lustrous coating, which is resistant to air and water.

It is used to improve the insulation properties, mechanical strength and to reduce degradation caused by oxidation and adverse atmospheric condition.

Classification of insulating materials on the basis of structure

Classification of insulating materials is done on the basis of their physical and chemical structure.

Table 2: Classification of materials on the basis of structure of material:

Classification	Insulating Materials
Fibrous material	Wood, paper, cotton, adhesive tapes
Insulating liquids	Transformer oils, cable oils, silicone fluids
Non-resinous material	Bitumen‟s, wax
Glass and ceramics	Glass, porcelain etc.
Plastics	Molding powder, rubber laminations
Mineral	Mica, micanites
Gaseous	Air, H_2, N_2, Ne, CO_2, SF_6, Hg and Na vapor

Table 3: Property and uses of some common electrical engineering materials

Material	Properties	Uses
Paper and press board	Low dielectric loss, Discharge current is lower	High frequency capacitors
Cotton	Hygroscopic, Low di-electric strength, properties can be improved by impregnation	Winding of small magnetic coil, Armature winding of coil and chokes
Wood	High dielectric constant, Highly hygroscopic, dry wood can bear a voltage gradient of 10kV/inch	Terminal block, wedges of armature winding, operating rods in high voltage switch gears.
Bitumen	Hydrocarbons of jet black colour, highly soluble in mineral oil, Poor insulating property, Low hygroscopic, Acid and alkali resistant	Underground cable
Waxes	Complex organic substance, High insulating property, Low hygroscopic	As impregnated material for paper and cloth insulation, dipping medium coating on conductors.
Glass	Organic material containing oxides, silicate and borate etc. Best insulating property, High resistivity and dielectric strength.	Insulating material to form envelope for internal support in bulbs, valves, X-ray tubes, fuse casings etc.
Ceramics	Hard, Strong, Dense, Unaffected by chemical action, Stable at high temperature, Excellent dielectric properties, weak impact strength	High voltage insulation at elevated temperatures in ovens.
Asbestos	Exhibit fiber structure , Can work at high temperatures, Good tensile strengths	Capacitor dielectric, transistor, hybrid circuit substrates, Electromechanical transducers, Not useful for high voltage, Used as thermal insulators and cables in high temperature.
Rubber	Stretchable, Moisture repellant, Good insulating properties, Good corrosion resistance. Can be obtained as hard rubber, synthetic rubber, butadiene rubber, butyl rubber, chloroprene rubber and silicon rubber.	Used as protective clothing such as boots and gloves, also used as insulation covering for wires and cables. Hard rubber is used in housing for storage batteries, panel board, jacketing material.

Special Solid Insulating materials: Properties and applications

MICA: two kind of mica are used as neutral insulating material in electrical engineering. Those are Muscovite mica and Phlogophite mica.

- ***Muscovite Mica**:* The chemical composition of muscovite mica is $KAI_3SiO_3O_{10}(OH)_2$. It is translucent green, ruby, silver or brown and is strong, tough and flexible. It exhibits good corrosion resistance and is not affected by alkalis. It is used in capacitors and commutators.
- ***Phlogophite Mica:*** The chemical composition of this is, $KMg_3AlSiO_3O_{10}(OH)_2$. It possesses less flexibility. It is amber, yellow, green or grey in colour. It is more stable, but electrical properties are poorer compared to Muscovite Mica. It is used in thermal stability requirements, such as in domestic appliances like iron, hotplates etc.

Polyethylene: It is obtained by polymerization of ethylene. The polymerization is performed in the presence of catalyst at atmospheric temperature and pressure around 100^0C. To obtain heat resistance property polythene is subjected to ionizing radiation.

Polyethylene exhibits good electrical and mechanical properties, moisture resistant and not soluble in many solvents except benzene and petroleum at high temperature. The dielectric constant and power factor remains steady over a wide range of temperature.

It is used as general purpose insulation, insulations of wires and cable conductors, in high frequency cables and television circuits, jacketing material of cables. Polyurethane films are also used as dielectric material in capacitors.

Teflon: The chemical name of Teflon is Polytetra fluoro-ethylene. This is synthesized by polymerization of tetra fluro ethylene. It bears good electrical, mechanical and thermal properties. Its dielectric constant is 2 to 2.2, which does not change with time, frequency and temperature. Its insulation resistance is very high and water resistant.

It is used as dielectric materials in capacitors, covering of conductors and cables, as base material for PCBs.

Polyvinyl Chloride (PVC): It is obtained by polymerization of vinyl chloride in the presence of a catalyst at 50^0C. PVC exhibits good electrical and mechanical properties. It is hard, brittle, and non-hygroscopic and can resist flame and sun light.

PVC used as insulation material for dry batteries, jacketing material for wires and cables.

Epoxy Glass: Epoxy glass is made by bonding two or more layer of material. The layers used reinforcing glass fibers impregnated with an epoxy rasin. It is water resistant and not affected by alkalis and acids.

It is used as base material for copper-clad sheets used for PCBs, terminal port, instrument case etc.

Bakelite: It is hard, dark colored thermosetting material, which is a type of phenol formaldehyde. It is widely used for manufacture of lamp holders, switches, plug socket and bases and small panel boards.

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Dielectric Material

Introduction:

The materials which are capable of retarding the flow of electricity or heat through them are known as dielectric or insulators. The safe handling of heat and electricity is almost impossible without use of an insulator. The material when used to prevent the loss of electrical energy and provides a safety in its operation is named as Electrical Insulating Material. The properties which are taken into consideration for an insulator are the operating temperature and breakdown voltage. However when it is used to store electrical charge, it is known as Dielectric Material.

The electrical conductivity of Dielectric material is quite low and the band gap energy is more than 3eV. This is the reason why the current cannot flow through them. The capacity of a capacitor can be increased by inserting with a dielectric material, which was discovered by Michael Faraday.

Dielectric Parameters:

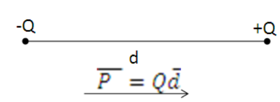
The knowledge of dielectric parameter is highly essential to choose the specific purpose dielectric for use. Those are *Dielectric constant, Dipole moment, Polarization and Polarizability.*

- ***Dielectric constant:*** The proportionality constant in the relation between the electric flux density (D) and the electric field intensity (E) is known as permittivity (ε) or dielectric constant. If the medium to which the electric field is applied is a free space (or vacuum), the proportionality constant of vacuum is ε_0 of value 8.854×10^{-12} farad.meter^{-1}. The dielectric constant of a material may be expressed as ε_r, relative to that of a vacuum by, $\epsilon_r = \frac{\epsilon}{\epsilon_0}$. So the relation of electric flux density and electric field intensity is given by,

$$D = \varepsilon_0 \varepsilon_r E$$

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

- **Dipole Moment:** Two charges (Q+ and Q-) of equal magnitude but of opposite polarity, separated with distance d, constitute a dipole moment , given as: **p** = Qd
  p is the dipole moment in coulomb-meter. Dipole moment is a vector pointing from the negative charge to the positive charge and its unit is Debye (1 Debye = 3.33×10^{30} coulomb-metre).



Dipole Moment

- **Polarization:** The dipole moment per unit volume is called the polarization **P**. $P = \frac{p}{volume}$; where p is the dipole moment and P is the polarization in coulomb.meter^{-3}.

  Considering a parallel plate capacitor having two metal plates of area A and separated in vacuum by distance d and having a battery of voltage V connected across it. The electric field E between the plates is given by V/d volt.m^{-1} arising from the charge density ±Q on the plates. The relation between Q and E is given by, $Q = \varepsilon_0 E$.

  Q can be considered as a source of electric flux lines in the space between the plates; the density of this flux lines is the electric displacement D.

  $$D = Q = \varepsilon_0 E.$$

  Now consider that the battery is still connected and a dielectric medium is introduced to fill the space between the plates. The medium becomes polarized by the field E and dipoles appear throughout the material, lined up in the direction of the field. All dipole ends of opposite charge inside the material will cancel, but there will be an uncompensated surface charge on the plates, Positive on one plate and the negative on the other plate. These surface charges will attract and hold corresponding charges of opposite sign on the plates because the latter, unlike dipoles are able to move freely. The field in the dielectric will be still E. If the effects of some of the original surface charges have been neutralized by being bound to surface dipole ends, E can only be maintained by the flow of more charges on the battery to compensate for those, which has become bound. There is now more charge density Q' on the plates some of which is tied up and is not contributing to the field E in the dielectric. The amount of charge that is contributing to the field is the same as before and $Q' = Q + Q_B$.

  Where Q_B is the bound charge density; Q has been multiplied by a factor ε_r such that $Q' = \varepsilon_r.Q$. Electric field density is now given by;

  $$D = \varepsilon_0 \varepsilon_r E$$

  $$or, D = \varepsilon_0 E + Q_B$$

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

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

  $$P = N.p\ ;$$

  Where N is the number of dipoles per unit volume.

- **Polarizability:** The application of an electric field to a dielectric material causes a displacement of electric charges giving rise to the creation or reorientation of the dipoles in the material. The average dipole moment 'p' of an elementary particle may be assumed to be proportional to electric field strength E, that acts on the particle so that; $p = \alpha E$

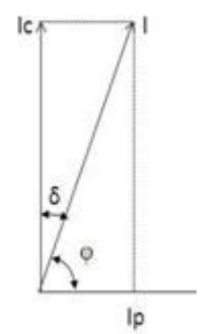
The proportionality factor α is called polirizability, measures the average dipole moment per unit field strength. The unit of the polarizability is farad.meter^2.

Mechanism of Polarization: The centre of gravity of positive charges and negative charges coincide in neutral atoms and symmetric molecules. When an electric field is applied to it, causes relative displacement of charges, leading to the creation of dipoles and hence polarization takes place. Un-symmetric arrangement of atom in a molecule results in a dipole even in the absence of an external field and in those cases the applied electric field tends to orient the dipole moments parallel to the field direction. The mechanism for forming the dipoles are categorized as (i) Electronic or Induced polarization, (ii) Ionic polarization, (c) Orientational polarization, (d) Interfacial or Space charge Polarization. Discussion of above mechanisms is restricted within the scope of the syllabus.

Dielectric Loss: The dielectric material separating the two electrodes or conductors is stressed when subject to a potential. When the potential is reversed, the stress also reversed. This change of stress involves molecularly arrangement within the dielectric. This involves the energy loss with each reversal. This is because the molecules have to overcome a certain amount of internal friction in the process of alignment. The energy expanded in the process is released as heat in the dielectric.

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

When a dielectric material is subjected to an ac voltage, the leakage current I does not lead the applied voltage E by exactly 90^0. As shown in vector diagram the phase angle ϕ is always less than 90^0. The dielectric loss can be calculated as follows:



$$P = E\, I\, cos\emptyset$$

$$where\ \ \emptyset = 90^0 - \delta\ and\ I = \frac{I_c}{\cos\delta}$$

$$\therefore P = E\,\frac{I_c}{\cos\delta}\,.\cos\ 90^0 - \delta\ = E\,\frac{I_c}{\cos\delta}\,.sin\delta = E\,I_c tan\delta = E.\frac{E}{X_c}tan\delta$$

$$Hence, P = E^2\,2\pi f c.tan\delta$$

δ is the complement angle to ϕ and is called dielectric loss angle. tanδ is the measure of dielectric loss known as dissipation factor. Good dielectric material should have very small dissipation factor yo minimize dielectric loss.

Factors affecting Dielectric loss: As observed from the equation of dielectric loss, the loss depends on the frequency and square of applied voltage. Dielectric loss increases with the presence of humidity and temperature rise.

Electrical conductivity of Dielectric and their Breakdown

The dielectric material is used in electrical and electronic circuits as insulators and as a medium in capacitors. When the applied electric field is increased, the potential difference across it also increases. A limit is reached when the dielectric ceases to work as an insulator and a spark occurs. This limiting value of the voltage is known as Breakdown Voltage, which measures the strength of dielectric.

$$Therefore, dielctric\ strength = \frac{Breakdown\ voltage}{Thickness\ of\ the\ dielectric}$$

Conduction of Gaseous dielectric: Air is the common gaseous dielectric. Cosmic rays and Ultraviolet rays cause the natural ionization in air. Since the opposite charges are equal, natural recombination takes place continuously to check further ionization of whole air.

The free charges do not go for recombination if the medium is within an Electric field. Due to application of the electric field, free charges move to their respective potential plates, causing a flow of current known as leakage current. The magnitude of current is dependent upon the applied voltage. With the increase in voltage the directed flow of electrons and ions increases as compared to random motion in low voltage. If the applied voltage is further increased, the energy of free charges becomes sufficient to force out electrons even from neutral atom. Each free electron moves at a great velocity, collides with other neutral atoms and knocks out free electron out of them. This process increases in geometric progression. The leakage current increases sharply in result to cause the breakdown of dielectric. The corresponding voltage is known as Breakdown voltage.

Conduction of Liquid dielectric: The liquid dielectric along with impurities of solid particle has more ability to conduct. The impurities get electrically charged and act as a current carrier. The fibrous impurities make the alignment of ions in a straight path for which the conductivity in liquid gets faster. In an uncontaminated liquid dielectric, such ion bridge cannot be formed. The breakdown of an uncontaminated liquid dielectric takes place due to the ionization of gases present in the liquid. The applied voltage ionizes the gas in liquid and the electric field intensity increases. It causes further ionization and ultimately the breakdown of dielectric takes place.

Conduction of solid dielectric: Electrical conductivity of solid dielectrics may be electronic, ionic or both. In electronics current flow the flow of current is due to the movement of electrons towards the positive electrodes, while ionic current flow is due to the movement of positively charged ions towards the negative electrode. The impurities also play the role of conductivity in the dielectric. At low temperatures, the conductivity of solid dielectric is due to the impurities only. At higher temperature the leakage current depends upon the contribution of free ions of the base dielectric.

Breakdown of solid dielectrics may be electro-thermal or electrical. The heat produced due to dielectric loss causes electro thermal breakdown and in effect destruction of dielectric takes place. If the dielectric is not able to radiate away the generated heat caused by dielectric loss and the applied voltage is retained for a long period the material gets melted. The electrodes get short circuited. Solid dielectric is not recoverable after its break down like liquid or gaseous dielectrics.

Properties of Dielectric Materials:

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

Material	Dielectric constant	Dielectric strength (kV/mm)	tan δ	Max working temp at 0^0C	Thermal conductivity (mW/mK)	Relative density
Air	1	3	-	-	0.025	0.0013
Alcohol	2.6	-	-	-	180	0.79
Asbestos	2	2	-	400	80	3.0
Cellulose film	5.8	28	-	-	-	0.08
Cotton fabric (dry)	-	0.5	-	95	80	-
Impregnated	-	2.0	-	95	250	-
Ebonite	2.8	50	0.005	80	150	14
Glass (flint)	6.6	6	-	-	1100	4.5
Glass (crown)	4.8	6	0.02	-	600	2.2
Mica	6	40	0.02	750	600	2.8

Dry Paper	2.2	5	0.007	19	130	0.82
Impregnated paper	3.2	15	0.06	90	140	1.1
Quartz	5.7	15	0.008	1000	1000	2.4
Vulcanized Rubber	4	10	0.01	70	250	1.5
Resin	3	-	-	-	-	1.1
Fused Silica	3.6	14	_	-	-	-
Silk	-	-	-	95	60	1.2
Sulphur	4	-	0.0003	100	220	2.0
Water	7.0	-	-	-	570	1.0
Paraffin Wax	2.2	12	0.0003	35	270	0.88

Application of Dielectrics:

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

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

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DIELECTRIC LOSS:-

Consider a parallel plate condenser filled with dielectric material characterised by r ' . Let the electrode area be 'A' and the plate separation be "d". The admittance of the capacitor for any angular frequency ω is given by =G+jB where G and B are the conductance and susceptance respectively.

Where C is the capacitance which may depend on frequency, because C=r ' A/d. The conductance G equals σA/d, where σ is an effective conductivity at the angular frequency ω. The conductance G arises because of the conversion of part of the electrical energy into heat, but mainly because of the complex dielectric constant.

Thus the absorption of energy by the material in an alternating field is proportional to the imaginary part of the dielectric constant. The dielectric is said to have losses which are characterised by the loss tangent.

In this circuit Īc is the conduction current which is responsible for the dielectric losses and is in phase with the applied voltage. Īd is the displacement current which is in phase quadrature with the applied voltage. Ī is the phasor sum of Īc and Īd. If there are no losses, r " is zero and the current Ī leads the applied voltage by 900 under these circumstances.

ELECTRIC CONDUCTIVITY OF DIELECTRICS AND THERE BREAK DOWN:-

Electrical breakdown or dielectric breakdown is a process that occurs when an electrical insulating material, subjected to a high enough voltage, suddenly becomes an electrical conductor and electric current flows through it.

The electric strength at breakdown is defined as the minimum electric stress usually expressed in KV/cm, waveform, frequency and the type of electrodes. The electric breakdown strength of a material depends on its composition, thickness, temperature, moisture content and to some extent on the time of application voltage. It is also affected by the shape of the waveform and the steepness of the waveform of the applied voltage. There is no definite relationship between these variables, but in general for sheet materials, the electric strength is an inverse function of the thickness and time and decreases with increases temp. And moisture content. At breakdown, the high electric stress is assumed to cause an interatomic displacement of the orbital electrons which alters the atomic structure causing heating and a conducting path in the material. The breakdown mechanism of gaseous, liquid and solid dielectrics are different in nature.

Gaseous Dielectrics:-

Breakdown in gases begins with the ionization due to collision of electron .In strong electric field The kinetic energy acquired by the accelerating free electron will be greater than the ionization energy of the gas. Collision ionization is started by the most of the mobile electron. The dielectric strength of gaseous dielectric depend on many factor. The electric strength is higher at very high and at very low pressure. The electric strength also depend on the uniformity of the applied electric field. When the electrode have different shapes the breakdown voltage depend on the polarity of the electrodes. The breakdown voltage depends on the frequency of the applied field. The other factors which influence the breakdown voltage of gas dielectric are the distance between the electrode and the chemical composition of the gas.

Liquid Dielectric:-

The breakdown mechanism of liquid dielectric depend on the purity of the dielectric. In the contaminated dielectric the breakdown occur due to the formation of conducting bridge between the electrode by droplet of emulsified water and suspended particles especially fibrous particles. The time taken to form the bridge depends on the extent of combination, the shape of the electrodes and gap between them. In technically pure liquid dielectric the break down is initiated by the ionisation of the gases in the liquid. All liquids dissolve a certain quantity of gas especially air. In degassed high purity liquid dielectric breakdown is evidently due to the collision ionization initiated by secondary electron emitted from the cathode due to the strong electric field.

PROPERTIES OF DIELECTRIC:-

Following are the exhibited by the dielectric materials:

- The energy gap in the dielectric materials is very large.
- The temperature coefficient of resistance is negative and the insulation resistance is high.
- The dielectric materials have high resistivity.
- The attraction between the electrons and the parent nucleus is very strong.
- The electrical conductivity of these materials is very low as there are no free electrons to carry current.

APPLICATION OF DIELECTRIC:-

Some of the applications of dielectrics are as follows-

- These are used for energy storage in capacitors.
- To enhance the performance of a semiconductor device, high permittivity dielectric materials are used.
- Dielectrics are used in Liquid Crystal Displays.
- Ceramic dielectric is used in Dielectric Resonator Oscillator.
- Barium Strontium Titanate thin films are dielectric which are used in microwave tunable devices providing high tunability and low leakage current.
- Parylene is used in industrial coatings acts as a barrier between the substrate and the external environment.
- In electrical transformers, mineral oils are used as a liquid dielectric and they assist in the cooling process.
- Castor oil is used in high-voltage capacitors to increase its capacitance value.

Electrets, a specially processed dielectric material acts as electrostatic equivalent to magnets

MAGNETIC MATERIAL

(CHAPTER 5)

- Materials which can be magnetised are called magnetic material
- When magnetised, such material creates a magnetic field around them.
- When current flows through a coil it creates an MMF. Does the circulating electron in a material also develop MMF In most material the direction of motion of the electron in various orbit is such that they develop MMF In opposite direction thus cancelling each other.
- In magnetic material there are a number ofunneutralised orbits which produce a resultant MMF creating magnetic poles called magnetic dipoles.
- In an unmagnetized material the Dipoles are scattered at random.
- In a magnetic material the dipole line of parallel with exciting MMF.
- The property of a material by virtue of which it allows itself to magnetised is called permeability.
- In magnetic material, the value of permeability is constant and is the same as for the free space.
- The permeability of free space is denoted by R_o and equals to $7\pi\times 10^{-7}$
- The permeability of air is almost same as for the free space i.e, $7\pi\times 10^{-7}$
- For magnetic material the permeability μ is given by $\mu = \mu_o \times \mu_r$. Where μ_r is called the relative Permeability.
  $B = \mu_o \times H$
- Relative permeability depends upon the nature of the material and on temperature.
- When relative permeability is positive the magnetic dipoles arranged themselves in the same direction as the applied field intensity.
- When relative permeability is negative the magnetic dipole is allign themselves in the opposite direction to the applied field.

The material are classified into:

1. **Magnetic material:**
   These material respond to an external magnetic field.
2. **Non-magnetic materials:**
   These materials Do not respond to an external magnetic field.

Magnetic metals are classified in:

1. Diamagnetism
2. Para magnetism
3. Ferromagnetism

- This classification is made on the manner they respond to external magnetic field.
- Diamagnetic and paramagnetic falls into the category of non-magnetic Materials.
- Ferromagnetic materials are classified as magnetic.

DIAMAGNETISM:

- Permanent magnetic dipole are absent in them because there is cancellation of magnetic fields due to electron rotating in opposite direction in the various orbit of the atom is total.
- Materials which lack permanent magnetic dipoles are called diamagnetic material.
- If an external magnetic field is applied to a diamagnetic materials it introduce a magnetism (M) in opposite direction to the applied field intensity (H).
- The relative permeability μ_r , of diamagnetic material is negative due to this reason diamagnetic material are not used in electrical engineering application.

For example: Silver, copper, bismuth, Hydrogen, etc.

PARAMAGNETISM:

- Many metals have small but positive relative permeability such material are called paramagnetic.
- The atomic dipoles are oriented in a random fashion.
- The resultant magnetic field is thus Negligible
- On application of an external magnetic field the permanent magnetic dipoles orient themselves parallel to the applied magnetic field and give rise to a positive magnetisation (M).
- The orientation of Dipole is parallel to the applied magnetic field is not complete therefore the magnetism (M) is small. The relative permeability of paramagnetic material are approximately unity. Thus paramagnetic material have negligible Application in the Field of electrical engineering.

For example: aluminium, platinum, oxygen, etc.

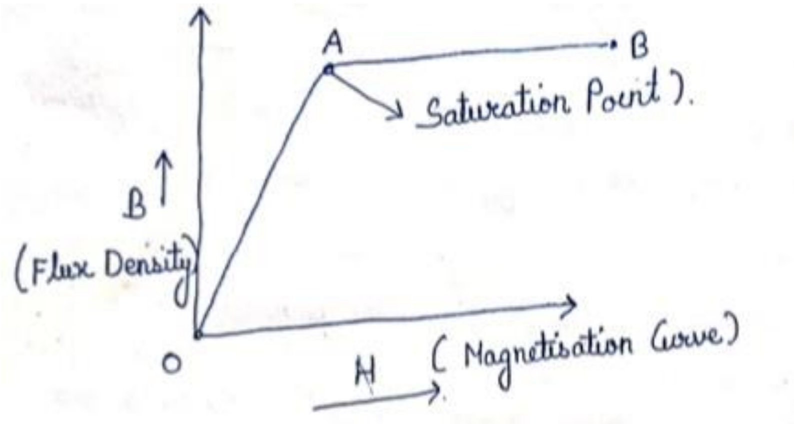
FERROMAGNETISM:

- Ferromagnetic material crystalline solids. The permanent atomic dipoles are aligned parallel to each other within group called Domains. Each domain is therefore at all times completely magnetised. When a weak external magnetic field is applied, it is not enough to cause any change in the orientation of dominance. The flux density with search low applied field is entirely Due to the externally applied magnetic field.
- When the externally applied Magnetic field is increased, stage where domain is still weak, it will start or renting themselves search that their resultant magnetic field coincides with the externally applied magnetic field and the material Will develop a strong magnetic field of it's own.
- There are some domains Who is original magnetic orientation greatly diverges from that of the applied Field and required a stronger external field to be Able to orient their magnetism in the same Direction as the applied field. i.e, determines whose original direction of magnetism is less divergent from that of the applied field, the rate

of strengthening of the internal magnetic field decrease with increase in the applied magnetic field and gives rise to magnetic saturation.

For example: Iron, cobalt, Nikel, etc

MAGNETISATION CURVE: -



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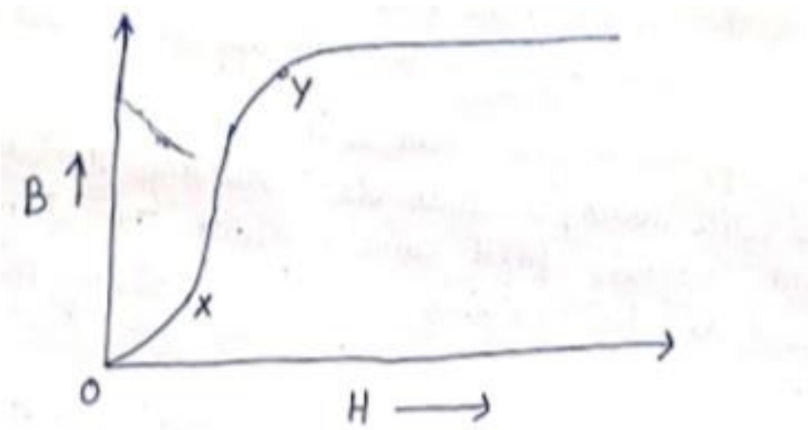
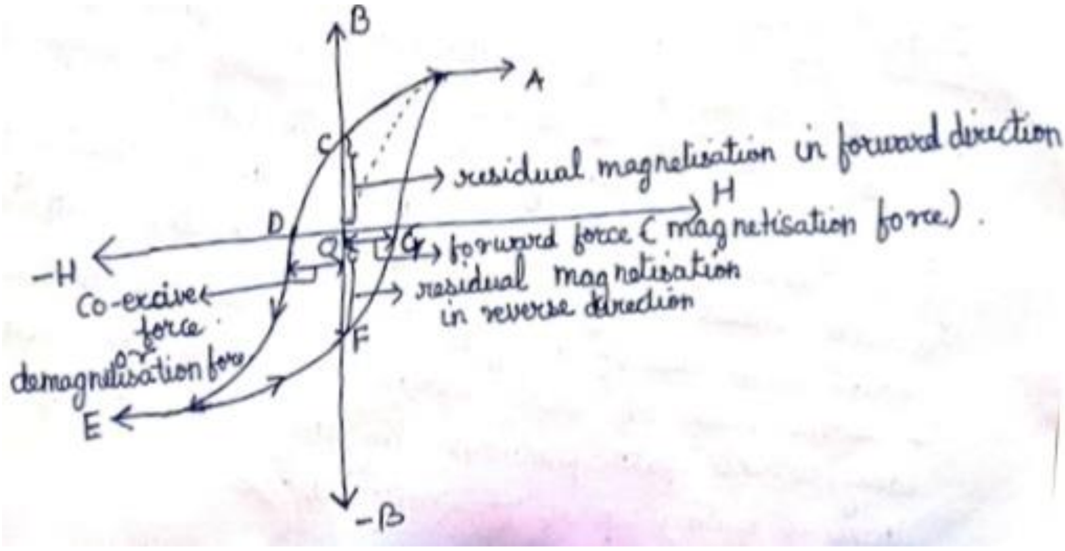


With very weak external field H, the flux density B, rise in direct proportion (i.e. as a straight line from origin).This means that during this reason up to the point X, the domains of the ferromagnetic material do not Orient themselves. Parallel to the applied field and therefore the material is not magnetized. The flux density is entirely due to the external field thus permeability of the material up to the point X is constant is called initial permeability. if the external field H is increased beyond the point X ,there is sharp increase in the flux density because the external field is strong enough to Orient parallel to its own axis. Up to point y the relative permeability of the material is not constant but keeps increasing.

when the magnetization curve reaches the point why the material is start saturating. After the curve becomes almost zero.

HYSTERESIS: -

- When ferromagnetic material the flux density B increases when external magnetic field applied to it is increased,when saturation arrives the increase in B almost cases even though H may be increased.
- If the external magnetic field is reduced it is found that the curve OA is not retraced.At H=0,the material is still magnetised and the flux density B has the value OC which is called residual magnetism.
- In order to demagnetize the material completely the external magnetic field H, is reversed when H reaches the value OD in the rivers to direction and BO in this time.Hence this applied magnetising force H in the reverse direction which causes B to be zero is co-ercive force. This force is also known as demagnetisation force.
- Further increase of H in the reverse direction will now increase B in the reverse direction and again at point E saturation occur.
- Again the external field is increased in forward direction and when H=0,her B=0 which is called the residual magnetisation.
- To neutralize the residual magnetization H is increased to the value of OG on the positive i.e the original direction. Further increase of H in the positive direction will again magnetise the material in this direction and saturation will occur at A.



- Flux density B always lags behind H
- this property of B lagging behind H is a characteristic of the magnetic behaviour of the ferromagnetic materials. 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 tracer loop ACDEFGA.this is called Hysteresis loop.

- when a ferromagnetic material is subjected to repeated cycles of magnetisationa loss occur this losses due to hysteresis is known as hysteresis loss this loss is directly proportional to the supply frequency.
- Hysteresis loss depends upon flux density and frequency of variation of flux and can be expressed as,

  Hysteresis loss=K $B_m^{1.6}$ f V_c watts

  Where K is a constant whose value depend upon the core material B_m is the maximum flux density of the magnetic field in which the core is placed.
- Magnetic core used in transformer and rotating electrical machines are made from materials whose hysteresis loops are narrow in order to keep down hysteresis loss.

EDDY CURRENT: -

Magnetic materials placed in alternating magnetic fields also have eddy currents induced in them. This is because the material is subjected to rate of change of flux linkage according to faradays law of electromagnetic induction E.M.F are induced in the material causing currents, called eddy currents, to flow in the material. These current causes 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. Due to the loss there is heating up of the material.

- The eddy current loss is proportional to the square Of frequency, square of the thickness of the material and inversely proportional to the resistivity of the material.
- To prevent Eddy current loss magnetic cores to be used in alternating magnetic field are built up on thin sheets of steel lamination separated from each other by thin film of insulation.
- The insulating film may be a cot of insulating varnish,a sheet of a paper or a film of oxide .
- An efficient insulation for silicon steel is a film of phosphate chemically deposited on the surface this film hold the high temperature annealing required by lamination punched out of sheets .This increases the resistance to the path of eddy current thus reducing their magnitude and eddy current loss.
- The losses due to hysteresis and Eddy current are also affected by the magnitude of the flux density hysteresis loss varies directly in proportional to B at low flux densities say upto 0.1Wb/m^2 to 1.0Wb/m^2 it is proportional to $B^{1.6}$.
- Eddy current losses are proportional to the square of flux density.

Eddy current loss=$KB^2mf^2t^2V_c$ watt

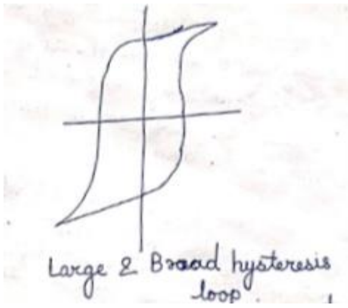
Where K is a constant which depend upon the core material amd t is thickness of the core lamination.

CURIE POINT:- The critical temperature above which the ferromagnetic materials losses their magnetic properties is called curie point.

At Curie point or Curie temperature the domain structure tend to disrupt and the domains lose their alignment, become arranged in random fashion thus the material loses its ferromagnetic property.

MAGNETOSTRICTION:- When ferromagnetic material are magnetised a small change of dimension of the material takes place there is a small extension with reduction of cross section of the crystal of which the material is made when subjected to rapid alternating magnetic field there is a rapid and continuous extension and contraction of the material. This is called magnetostriction.

All ferromagnetic materials are divided into two groups:

SOFT MAGNETIC MATERIAL	**HARD MAGNETIC MATERIAL**
• Materials which has a steeply rising magnetization curve ,relatively small and narrow hysteresis loop and small energy losses during cyclic magnetisation are called soft magnetic material.  • Used in building cores for use in alternating magnetic fields. • Eg-soft pure iron,siliconiron,alloy,nickel iron alloy and soft ferrites. • Used in construction of cores in electric-machine,transformers,electro-magnets,reactors,relays etc. • They have small enclosed area of hysteresis loop. • High permeability. • High saturation value of flux.	• Magnetic materials which have a gradually rising magnetization curve large hysteresis loop and large energy losses during cyclic magnetisation are called hard magnetic material.  • Used for making permanent magnets. • Eg-carbon steel,tungstensteel,cobaltsteel,alnico, hard ferrites • They have high saturation values,highcoersive force and high residual magnetisation.

Example of soft magnetic material:-

1.Pure iron:-It is a ferrous with an extra lower carbon content.eg-low carbon steel and electrolyte iron.in low carbon steel the carbon content is less than 0.1%.it has high magnetic permeability.

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

Pure iron is widely used in electrical apparatus and instrument as magnetic material care for electromagnets,components for relay electrical instruments etc.

Pure iron is not used in rotating electrical machine where rotation of the slotted rotor cause variation in reluctance .

2.Iron silicon alloy:-The application of pure iron is limited because of its high eddy current losses.so by adding 0.5to 5%by weight of silicon in to iron is known as iron silicon alloy usually called silicon steel.

It is used for strong alternating magnetic fields generally used in transformer,electrical rotating machine,reactors,electromagnets and relays.

Silicon sharply increase the electrical resistivity of iron thus decreasing the iron losses due to eddy current .it increase the permeability at low and moderate flux densities but decreases it at high densities.

Addition of silicon to iron reduces the hysteresis loss. The magnetostriction effect is also reduced.

By addition of silicon into iron its improved the magnetic properties of iron and fasilates the steel making process.

Alloying of carbon steel with silicon increases the tensile strength, it reduces ductility mobbing steel brittle.

The silicon alloyed steel difficult to perch and sheathe .a steel with more than 5%silicon may be too hard and brittle.

The care are made up silicon alloy to reduce the hysteresis loss and care is laminated to minimum the eddy current loss.

GRAIN ORIENTED SHEET STEEL:-

Grain-oriented electrical steel usually has a silicon level of 3% (Si:11Fe). It is processed in such a way that the optimal properties are developed in the rolling direction, due to a tight control (proposed by Norman P. Goss) of the crystal orientation relative to the sheet.
The magnetic flux density is increased by 30% in the coil rolling direction, although

its magnetic saturation is decreased by 5%. It is used for the cores of power and distribution transformers, cold-rolled grain-oriented steel is often abbreviated to CRGO.

CRGO is usually supplied by the producing mills in coil form and has to be cut into "laminations", which are then used to form a transformer core, which is an integral part of any transformer.

NICKEL AND IRON ALLOYS:-

• Iron and iron nickel alloys have low critical permeability. For power application like transformers and rotating electrical machines where core materials are operated at high flame densities the initial permeability is of no importance. Put for high sensitivity and low distortion needed in communication systems. The iron and silicate alloys are not suitable.

• In special magnetic alloys having initial and maximum permeability are used for special application like instrument transformers, relays etc. A group of iron alloys containing nickel between 30 to 80 percent with possible selection is molybdenum and chromium when given appropriate treatment during manufacture, show very high permeability's at low flux densities and much lower losses then iron. The important alloys in this category are permalloy , super alloy and mumetal. Permalloy: This is used in manufacture of sensitive relays. The curie tempertature of this group of material varies between 420 degrees to 580 degrees depending on the percentage of nickel content and heat treated upto about 1050to 1100 degrees celisus. It has initial permeability between 2500 to 8000 as well as maximum permeabilities is 1,00,000. Superalloy: It consists of iron and nickel alloyed with copper and molybdenum. This alloy has high initial permeability upto 1,00,000. Mumetal: It consist of iron and nickel alloyed with copper and chromium. It is used for manufacture instrument transformer and miniature transformer used in communication circuits. Its initial permeability is 20000 and maximum permeability is 110,000. Its curie temperature is 130 degree Celsius.

• **Super ferrites**: Ceramic magnets, also called ferromagnetic ceramics and ferrites are made of Iron Oxide Fe_2O_3 with one or more divalent oxides such as NiO,MnO,ZnO.This magnets have a square hysteris loop and high resistanc to demagnetization and are used for computing machines where high resistance is required.They have high resistivity and reduced eddy current. Ferrites are made by mixing powdered oxides,compacting and sintering at high temperature.Ferrites cores are used in high frequency transformer in television and frequency modulated receiver. Ferrites with large magnetostriction effect are sometimes used in electromechanical transducer. In high frequency application,magnetostruction in ferrites can lead to undesirable noise.

Examples of Hard magnetic material:

Hard magnetic materials are made up of permanent magnate

1. Carbon steel, tungsten steel and cobalt steel :Soft magnetic material cannot be used for making permanent magnets because they have narrow hysteresis loops. when Carbon is added in a material, the hysteresis loop area is increased i.e. Carbon steel was used for permanent magnet. It is cheap, magnets made from carbon steel lose their magnetic properties very fast sunder the influence of knocks and vibration.

When materials like tungsten, chromium or cobalt are added to carbon steel, its magnetic properties improved. Cobalt steel has superior magnetic properties but it is expensive.

2.Alnico: Alloys like ALNICO(Aluminium-nickel iron cobalt) are hard magnetic materials.They are hard magnets used in many electrical engineering applications i.e. in various measuring instruments.

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

MATERIALS FOR SPECIAL PURPOSES

Some materials used for special purposes such as fuses, solder, bimetal, storage battery plates. Those materials used for special purposes are in structural materials or protective materials.

STRUCTURAL MATERIALS :

Cast iron, steel, timber, reinforced concrete are common materials for this purpose.

Cast iron is used as materials for the frames of small and medium sized electrical machines. Steel is used in fabricated frames in large electrical machine, tanks in a transformers, fabrication of transmission towers.

Timber and reinforced concrete are used for poles in OH lines.

PROTECTIVE MATERIALS :

LEAD :

Lead is soft, heavy and bluish grey metal. It is highly resistant to many chemical action, but it can corrode by nitric acid, acetic acid, line and rotten organic substance. The electrical conductivity is 7.8% of copper. Lead is used in storage batteries and sheathing of cables. Pure lead cable sheathing are liable to fail in service due to formation of cracks formed because of vibration.

Lead alloys with tin and zinc and forms alloys which are used for solders and bearing metals.

STEEL TAPES, WIRES AND STRIPS :

Steel tapes, wires and strips are used as protective materials for mining cables, underground cable, weather proof cables.

<u>OTHER MATERIALS :</u>

THERMO COUPLE MATERIALS :

When two wires of different metals are joined together an emf exist across the junction. This emf is directly proportional to the temperature of the junction. When one tries to measure this emf more junctions are to be made which will give rise to emfs. When all the junctions are at the same temperature, the resultant emf will not be zero. This resultant emf is proportional to the temperature difference of the junctions and is known as thermoelectric emf.

Thermo couples are made of different materials such that copper / constantan, iron / constantan, platinum / platinum rhodium.

Thermo couples can be used for the measurement of temperature.

BIMETALS :

A bimetal is made of two metallic strips of unlike metal alloys with different coefficient of thermal expansion. At a certain temperature the strip will bend and actuate a switch or a lever of a switch. The bimetal can be heated directly or indirectly. When heated the element bends so that the metal with the greater coefficient of expansion is on the outside the are formed while that with smaller coefficient is on the inside.

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

SOLDERING MATERIALS :

An alloy of two or more metals of low melting point used for base metals is known as soldering. The alloy used for joining the metals is known as solder. The solder is composed of 50% lead and 50% tin. Its melting point is 185ºC tensile strength is 385 kg./cm^2 and electrical conductivity is 10% of copper.

For proper soldering flux is to be used. In soldering process the application of flux serves to removes oxides from the surface to be soldered. They deoxidize the metals at the time the soldering element is added. Solders are two types such as soft solders and hard solders soft solders are composed of lead and tin in various proportions. Hard solders may be any solder with a melting point above that of lead tin solders.

The application of soft solders is in electronic devices and hard solder in power apparatus for making permanent connection.

EYRE NO.7 FLUX :

It is an improved variety of organic flux which is used with Alca P for alumnimum cable jointing. This on decomposition at a temperature a little below the jointing temp approx 316ºC removes the refractory oxide from the strands of the core and makes the surface receptable to solder.

FUSE :

A fuse is a protective device, which consists of a thin wire or strip. This wire is placed with the circuit which heave to protect, so that the circuit. Current flows through it. When this current is too high the temperature of the wire or strip will increase till the wire or strip melts. So braking the circuit and interrupting the power supply.

FUSE MATERIAL :

A fuse material have following properties :

a. Low resistivity
b. Low conductivity
c. Low melting point

As lead is used as fuse material because of its low melting point. But the resistivity of lead is high, thick wires are used. For rewirable fuses alloys of tin and lead are used.

DEHYDRATING MATERIAL :

SILICA GEL :

It is an in organic chemical, a colloidal highly absorbent silica used as a de-humidifying and dehydrating agent as a catalyst carrier. Calcium chloride and silica gel are used in dehydrating breathers to remove moisture from the air entering a transformer as it breathes. Now silica gel is used for breather of a transformer. Its main advantage is that when it becomes saturated with moisture it does not restrict breathing. Silicagel when dry is blue in colour and the colour changes to pale pink as it becomes saturated with moisture.