CONTENT GENERATION UNDER EDUSAT PROGRAMME

Electrical Engineering Material (EET-302)

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Conducting Materials

1. Introduction

An electrical engineer should posses the knowledge of the properties of materials used in electrical engineering. This knowledge helps to choose the correct materials for a given application. Hence, the materials available can be employed effectively and economically for a specific purpose.

2. Classification of Electrical Materials

- **Materials used in the electrical engineering field are classified basing on their properties and applications.**

  a. Conductor materials.

  b. Resistor materials.

  c. Insulating materials.

  d. Semiconductor materials

  e. Magnetic materials

  f. Refractory materials

  g. Structural materials.

- **Classification of Materials Based on Atomic Structure**

The materials such as gold, silver, copper and aluminium which can neither be broken into other substances nor be created are called ‘elements’. The smallest particles into which an element can be divided having the identity of the element are called ‘atoms’. These particles cannot be divided further. The atom although extremely small, has a complex internal structure of its own. This resembles the miniature solar system. An atom consists of the central core called nucleus, with electrons revolving around it as well as spinning around themselves. The nucleus contains protons and neutrons. Each proton possesses as much positive charge as an electron possesses negative charge (1.6×10^{-19} C). The number of protons inside the nucleus is equal to the number of electrons revolving around it. This number is called atomic number of the element. The neutron does not possess any charge. Therefore, the atom is electrically neutral. The mass of a proton or a neutron is 1.672 x 10^{-27} kg. which is 1850 times more than that of an electron. The mass of an electron is 9.107 x 10^{-31} kg. The electron's diameter is three times that of a proton. The weight of *protons and neutrons together* is called *atomic weight* of the element. The electrons are held in the atom by attractive force between protons and electrons which carry opposite charges. The electrons revolve in successive orbits or shells. The orbits should be visualized to be in different planes and not as they appear to be in the figure. The number of electrons that each shell can accommodate is given by $2n^2$, where n is the number of the shells counting from the innermost shell. The innermost shell (i.e. the first shell) can accommodate 2 electrons, the second shell 8, the third 18 and so on. The outermost shell in no case will contain more than 8 electrons in the first shell, 8 in the second, 8 in the third and 1 in the fourth even though the third shell can accommodate 18 electrons according to the formula.

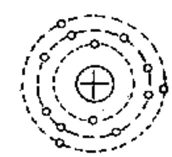


Fig 2.1

Within the shell there are sub-shells which are classified as : s, p, d, f, g, s and p and so on. There are energy levels again in these sub – shells. The sub-shell s has one energy level, p has three levels, d has five levels and so on. Not more than two electrons occupy the same energy level, one spinning in one direction and the other in the opposite direction. Thus the sub-shell

S can accommodate 1 x 2 = 2 electrons
P can accommodate 3 x 2 = 6 electrons
D can accommodate 5 x 2 = 10 electrons
F can accommodate 7 x 2 = 14 electrons
G can accommodate 9 x 2 = 18 electrons
and so on.

Shell	Possible sub-shells
1 or K	1s
2 or L	2s 2p
3 or M	3s 3p 3d
4 or N	---------
5 or O	---------
6 or P	6s 6p 6d 6f 6g 6h

According to Pauli exclusion principle, the state of any electron is defined by four Quantum numbers :

a) The shell number 1,2,3, etc. of K,L,M,N, etc.,

b) The sub-shell number s,p,d,f,g etc.

c) The orbit number in sub-shell 1s, 2s, 3s, etc., and

d) The electron spin Quantum number +1/2 and -1/2

The electrons nearer to nucleus are more firmly held than those farther from it. The energy required to pull out one electron from the first orbit is more than the energy required to pull out one electron from the second orbit and so on. That is, electrons possess a definite amount of energy, called quantum, depending upon the orbit. Hence, orbits are referred to as energy levels. The valency of an element is determined by the number of electrons it can receive or give away from its outermost sub-shell to another element in a reaction. The elements having 3 or less valency electrons, give away these electrons but elements having 5 or more valence electrons, do receive such electrons to make the total as 8, for stability. The valence electrons are very loosely held and contribute to the properties of the element. If the valence orbit contains 8 electrons, then the atom is complete and stable; if it contains less than 8, the atom is unstable and very easily gives out or receives valence electrons from the neighbor to complete its valence orbit.

3. Inter-atomic Bonds: Conductor, Semiconductor and Insulator

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

The first one 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 called ***covalent bond***. In this bond, the atoms of the materials having 4 or more valency electrons share their electrons with neighbouring atoms as shown in Fig. 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***.

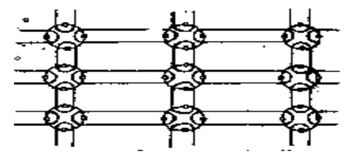


Fig 2.2

The third 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*****.**

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.

4. Conductor Materials

- **Resistivity-**. Resistivity or specific resistance of a material may be defined as the resistance offered between the opposite faces of a metre cube of that material. The unit of resistivity is ohm metre (Ω-m). We have according to law of resistance:

  The resistance of a material (R) depends-

  - directly to its length (L)

  -inversely to the ‘X’-sectional area (A)

So, R α L / A

Or R= ρ L/A (where ρ is known as resistivity of material)

Therefore ρ = A R/L

When R= Resistance in Ohms (Ω)

L= Length in m

A= Area of cross section in m^2

ρ = resistivity or Specific resistance in Ω-m

- **Temperature Coefficient of Resistance**.

Based on temperature effect, electrical materials can be classified into two groups (i) positive temperature coefficient materials and (ii) negative temperature coefficient materials.

(i) Positive temperature coefficient means that the resistance of some of the metals and alloys increases when their temperature is raised.

(ii) Negative temperature coefficient means that the resistance of some of the materials, i.e., carbon and insulators and electrolytes, decreases when their temperature is raised.

If the resistance of a conductor is R_0 at 0^0 C, then its resistance at t^0C is given by the equation $R_t = R_0\ \alpha\ t$ where α is the temperature coefficient of resistance at 0^0C and t is the difference in temperature.

While selecting a material for a specific purpose in electrical engineering, its electrical, mechanical and economical properties are to be considered.

5. Properties of Conductors

A. *Electrical Properties*

1. The conductivity must be good.
2. Electrical energy displayed in the form of heat must be low.
3. Resistivity must be low.
4. Temperature resistance ratio must be low.

B. ***Mechanical Properties***

1. Ductility: It has that property of a material which allows it to be drawn into a wire.
2. Solderability: The joint should have minimum contact resistance.
3. Resistance to corrosion: Should not get rusted when used in outdoors.
4. Withstand stress and strain.
5. Easy to fabricate.

C. ***Economical Factors***

1. Low Cost
2. Easily Available.

6. **Superconductor**

- Theory of super conductor.

When a piece of tin is taken and cooled down to a temperature T_c = 3.7 K, we find that below T_c, the tin is in a new thermodynamic state. The change that has occurred in the metal is not a change in the crystallographic structure. It is not even a ferromagnetic or anti-ferromagnetic transition. The resulting new property is that the tin has zero electrical resistance at this state. In fact, a current induced in a tin ring at temperature T_c has been observed to persist over a period of more than one year. We say that tin, in this particular condition, is a Super Conductor.

A large number of metals and alloys are superconductors, with critical temperatures T_c ranging from less 1K to 18K. Even some heavily doped semiconductors have been found to be superconductors. Historically, the first superconductor to be discovered was mercury- discovered by Kammerling Onnes in 1911.

Superconductors are by no means rare. More than 20 elements, all metals, are superconducting, and so are innumerable alloys and intermetallic compounds. Curiously enough, the best conductors like silver, copper and gold are not superconductors. Superconductivity depends on

a) electron-proton interaction, and

b) critical temperature.

- Applications.
- Superconductors can be used for the production of strong magnetic fields. Magnetic inductions in the order of 10 Wb/m^2, far above the largest value obtainable with iron-core electromagnets, have been obtained in superconducting solenoids. Other applications of superconductors are based on the effect of an applied magnetic field on the transition between normal and superconducting states. e.g. at a constant temperature below T_c, changes back and forth from normal to superconducting behavior can be affected by varying the external magnetic field, which thereby can control the current in a circuit connected to the superconductor. Thus, amplifiers, oscillators, control systems, and especially the logic and information storage functions of a large-scale computer can be provided by the controlling magnetic field exercises on superconductivity.

7. Characteristics of a Good Conductor Material

The conductor materials should have low resistivity so that the desired of a conductor material depends on the following factors :

1. Resistivity of the materials.
2. Temperature coefficient of resistance
3. Resistance against corrosion
4. Oxidation characteristics
5. Ease of soldering and welding
6. Ductility
7. Mechanical Strength
8. Flexibility and abundance
9. Durability and low cost
10. Resistance to chemicals and weather

8. **Low Resistivity Materials and their applications**

- ***Copper***

<u>Properties :</u>

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 $108^{4}0C$.
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**

It is best known electrical conductor.

<u>Properties</u>

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**

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 20^0C.

4. It is good conductor of heat and electricity.

5. Its specific gravity is 2.7.

6. Its melting point is 658^0C.

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.

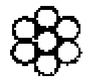
- **Bundled Conductors & Underground Cables**.

Conductor Materials for Overhead Lines : Electrical and Mechanical Properties

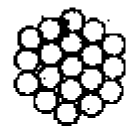
The function of overhead lines is to transmit electrical energy. The important properties which the line conductors must have are :

1. High electrical conductivity.
2. High tensile strength.
3. Low density.
4. Low cost.

Bundling of conductor increases the electrical and mechanical properties in comparison to the solid conductors. It is called as stranding. The number of strands in cables are 7. 19, 37, 61, 91, 127 or 169 as these conductors give the cylindrical formation.



1 + 6 = 7 Strands



1 + 6 + 12 = 19 Strands

Copper conductor used for transmission is hard-drawn copper.

Properties.

1. It has the best conductivity.
2. It has high current density.
3. The metal is quite homogeneous.
4. It has low specific resistance.
5. It is durable and has high scrap value.

Aluminium is next to copper to be used as a conductor.

Properties :

1. It is cheaper than copper.
2. It is lighter in weight.
3. It is second in conductivity.
4. For the same ohmic resistance, its cross-section is about 1.27 times that of copper.
5. At higher voltages, it causes lower coronal loss.

6. As the diameter of the conductor is more, it is subject to greater wind pressure due to which the swing of the conductor and sag will be greater.
7. Since the conductors are liable to swing, it requires larger cross-section.
8. As the melting point of the conductor is low, the short-circuit current will damage it.
9. Welding of aluminium is much more difficult than that of any other material.

Aluminium Conductor with Steel Reinforcement (ACSR). An aluminium conductor having a central force of galvanized steel wires is used for high-voltage transmission purposes. Reinforcement is done to increase the tensile strength of aluminium conductor.

The galvanized steel core is covered by one or more strands of aluminium wires. Steel conductors used are galvanized in order to prevent rusting and electrolyte corrosion. The cross-sections of the two metals are in the ratio 1:6. For high-strength conductor, their ratio is 1:4. The steel-reinforced aluminium conductor has lower sag and longer span than the copper conductor line since it has high tensile strength. The ACSR conductor has a larger diameter than any other type of conductor of same resistance. For all calculation purposes, it is assumed that the current is passing only in the aluminium section.

Cable

Electrical and mechanical properties : Cables are most useful for low-voltage distribution in thickly populated areas. The advantages of cables are : The cable transmission is not subjected to supply interruption caused by lightning or thunderstorms, birds and other sever weather conditions. It reduces the accidents caused by breaking of the conductors. Its use does not spoil the beauty of cities.

1.10.2 Required Properties of Cables.

1. High insulation resistance.

2. Moisture and water percolated due to rain or other causes should not come in contact with conductor.

3. Low discharge current.

4. Sufficient strength for mechanical handling and cable laying.

5. Resistant to chemical action due to chemical content in earth or damages due to insects.

6. As there is not much opportunity for heat dissipation from conductor, the insulator must be capable of withstanding, without any change in qualities, the temperature within the cable.

7. It must be flexible, light and occupy less space.

8. Available in right quantity and at low rate.

Materials Used for Manufacturing Cables are Paper (impregnated), varnished cabric, vulcanized bitumen, rubber, compressed air, petroleum jelly, metal sheath (lead or lead alloy), galvanized steel or tapes for armouring and jute.

10.High Resistivity Materials and their applications

- **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^{0}C 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^{0}C.
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 special-purpose vacuum tubes.
3. Platinum-rhodium thermocouple is used for measurement of temperatures up to 1600^{0}C.

- **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 300^0C 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.

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.***

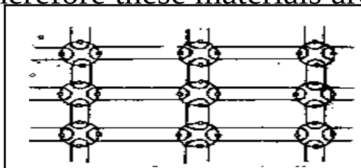


Fig 3.1

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.

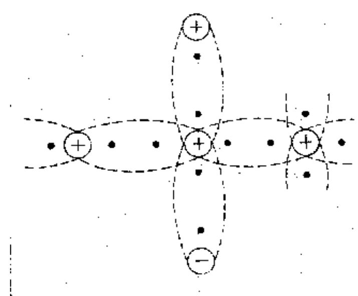


Figure -3.2 Set of covalent bond

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.

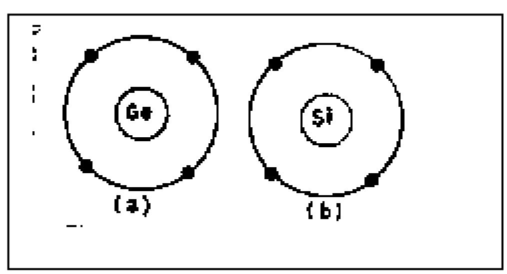


Figure -3.3 (a) simplified silicon and germanium atom

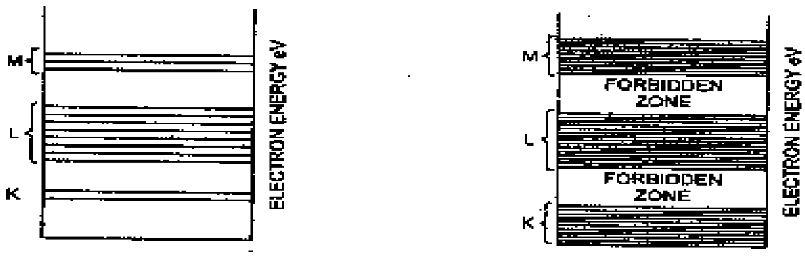


Figure -3.3 (b) Energy band representation of ionisation

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.

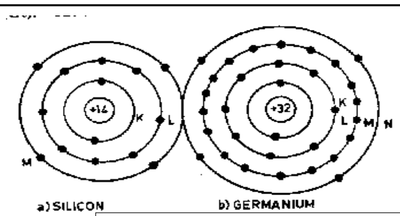


Fig- 3.4 Shell arrangement

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.

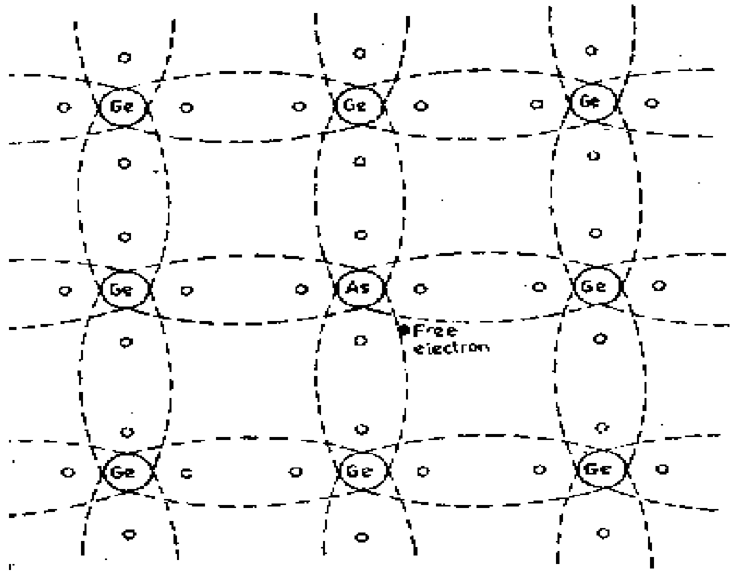


Fig- 3.5 Arsenic impurity atom provides a fifth electron

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.

Semiconductors Commonly Used

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

Intrinsic Semiconductors.

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.

Extrinsic Semiconductors.

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

Germanium and Silicon Rectifiers. 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.

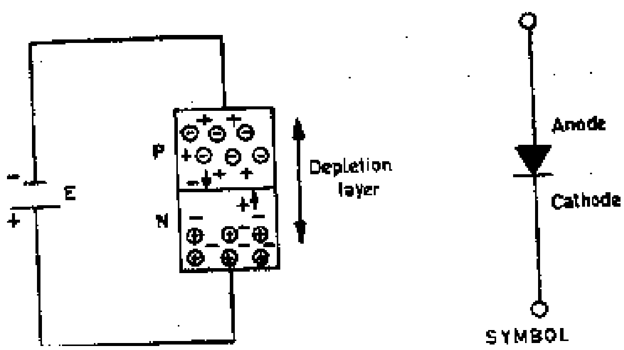


Fig-3.6 a The operation of PN junction under reverse bias

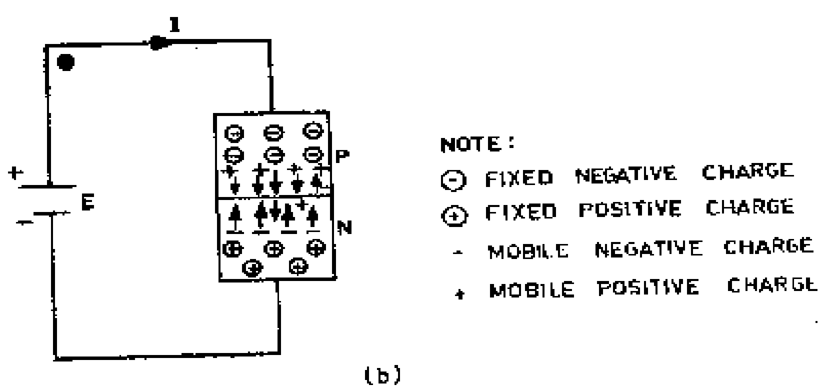


Fig- 3.6 b The operation of PN junction under forward bias

- **Copper Oxide Rectifiers**. 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.

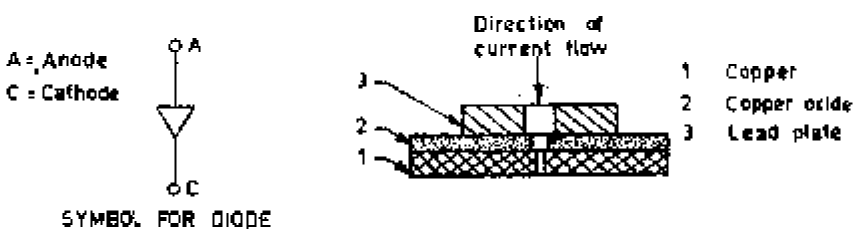


Fig- 3.7 **Copper oxide rectifier**

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.

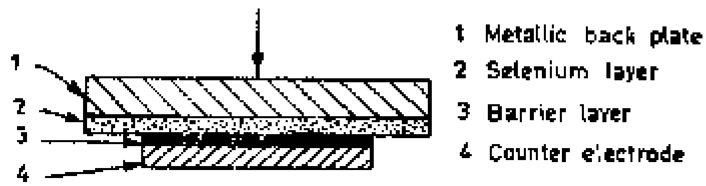


Fig-3.8 Selenium rectifier

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.

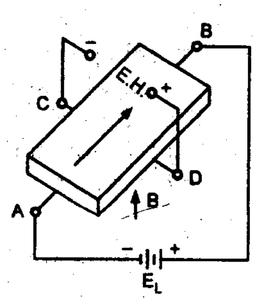
Applications. They are used in voltage stabilizers and for motor speed control.

- **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.

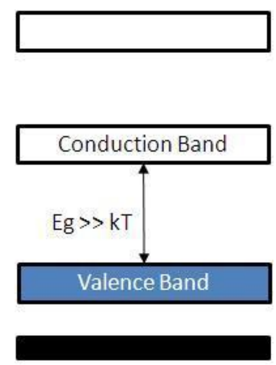


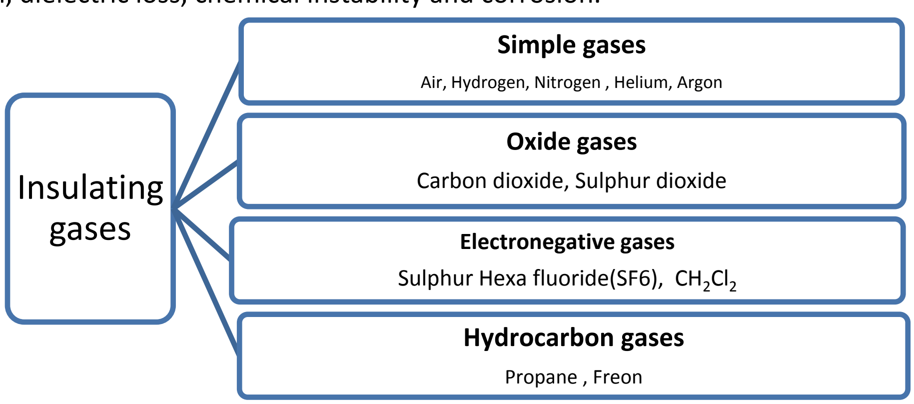
Figure 1. Energy band of INSULATOR

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.

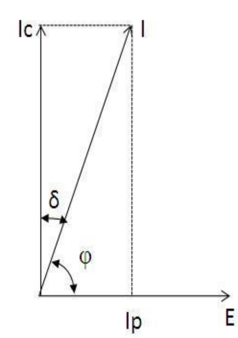


Figure 2. Plot of E against Ic

- 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 50-110^0C. 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 130^0C, 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.

****

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:

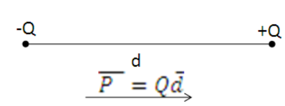
The knowledge of dielectric parameter is highly essential to choose the specific purpose dielectric for use. Those are *Dielectric constant, Dipole moment, Polarization and Polarizability.*

- ***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; $p = \alpha E$

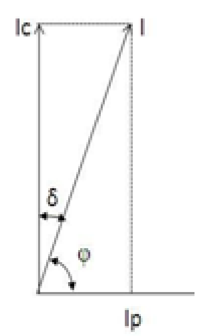
The proportionality factor α is called polirizability, measures the average dipole moment per unit field strength. The unit of the polarizability is farad.meter^2.

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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MAGNETIC MATERIALS

Materials in which a state of magnetization can be induced are called magnetic materials when magnetized such materials create a magnetic field in the surrounding space.

The property of a material by virtue of which it allows itself to be magnetized is called permeability. The permeability of free space is denoted by μ_o. Its value $\mu_o = 4\pi \times 10^{-7}$.

The material permeability $\mu = \mu_o \times \mu_r$

When μ_r = Relative permeability

Classification of Magnetic materials :

Magnetic materials classified as :

a. Diamagnetic material
b. Para-magnetic material
c. Ferro-magnetic material

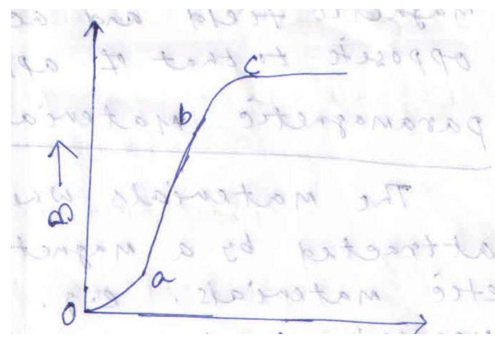
DIAMAGNETIC MATERIAL :

The materials which are repelled by a magnet are known as diamagnetic materials. Eg. Zinc, Mercury, lead, Sulphur, Copper, Silver. Their permeability is slightly less than one. They are slightly magnetized when placed in a strong magnetic field and act in the direction opposite to that of applied magnetic field.

PARAMAGNETIC MATERIALS :

The materials which are not strongly attracted by a magnet are known as paramagnetic materials. Eg. Aluminium, Tin, Platinum, Magnesium, Manganese, etc. Their relative permeability's is small but positive. Such materials are slightly magnetized when placed in a strong magnetic field and act in the direction of the magnetic field.

In paramagnetic materials the individual atomic dipoles are oriented in a random fashion. So the resultant magnetic field is negligible. When an external magnetic field is applied. The permanent magnetic dipoles orient themselves parallel to the applied magnetic field and give rise to a positive magnetization.



FERRO-MAGNETIC MATERIALS

The materials which are strongly attracted by a magnet are known as ferro-magnetic materials. Their permeability is very high. Eg. Iron, Nikel, Cobalt, etc. The opposing magnetic effects of electron orbital motion and electron spin do not eliminate each other in an atom of such a material.

MAGNETISIATION CURVE :

The curve drawn giving relationship between induction density 'B' and magnetizing force 'H' is known as magnetization curve or B ~ H curve.

This figure shows the general shape of B ~ H curve of magnetic material. In general it has four distinct regions oa, ab, bc and the regions beyond c. During the region oa the increase in flux density is very small, in region ab the flux density B increases almost linearly with the magnetizing force H, in region bc the increase in flux density is again small and in region beyond point c, the flux density 'B' is almost constant. The flat part of the magnetization curve corresponds to magnetic saturation of the material.

HYSTERSIS :

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

If a magnetic substance is magnetized in a strong magnetic field it retains some portion of magnetism after the magnetic force is withdraw. The phenomenon of lagging of magnetization or induction flux density behind the magnetizing force is known as magnetic hystersis.

The losses due to hystersis is known as hystersis loss. Hystersis loss depends upon the maximum flux density 'B_m' and frequency of variation of flux is expressed as :

Hysteresis loss = $\eta B_m^{1.6} fv$ J/S or Watt.

Where η = is a constant. It is known as steinmetz hystersis coefficient

f = frequency of reversal of magnetization

B_m = Maximum flux density

V = Volume of magnetic material

EDDY CURRENT AND EDDY CURRENT LOSS :

When magnetic material is placed in alternating magnetic field, it cuts the magnetic flux. According to laws of electromagnetic induction an emf is induced. This emf causing current is known as Eddy current. The power loss due to the flow of this current is known as Eddy current loss.

Eddy current loss is proportional to the square of the frequency and the square of the thickness of the material and is inversely proportional to the resistivity of the material.

The expression for Eddy current loss is :

Eddy current loss = $KBm^2f^2t^2v^2$ Watt

Where Bm = Maximum flux density

f = Frequency of magnetic reversal

t = Thickness of lamination

v = Volume of magnetic material

CURIE POINT :

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

SOFT AND HARD MAGNETIC MATERIALS :

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

a. Soft-magnetic materials
b. Hard magnetic materials

Materials which have a steeply rising magnetization curve, relatively small and narrow hysteresis loop and consequently small energy losses during cyclic magnetization are called as soft magnetic materials. Soft magnetic materials are soft-iron, nickel iron alloys and soft ferrites.

Magnetic materials which have a gradually rising magnetization curve, large hysteresis loop and consequently large enrgy loss of each cycle of magnetization are called hard magnetic material. Such materials are used for making permanent magnet. The examples of hard magnetic materials are carbon-steel, tungsten-steel, cobalt steel, alnico, hard ferrites.

SOFT MAGNETIC MATERIALS :

Soft magnetic materials are used for the construction of crores for electric machines, transformers, electromagnets, reactors, relays.

In order to keep the magnetizing current and iron losses low using a low flux density. It increases the cross-sectional area of magnetic path.

The magnetic material for the core of electrical machines and transformers should have high saturation value and high permeability to keep the magnetizing current within reasonable low values. When the core is to be used for alternating magnetic fields the core should be a such material as to produce small iron losses.

PURE IRON :

Pure iron is a ferrous material with an extra-low carbon content. Eg. Low-carbon steel, electrolytic iron. The resistivity of pure iron is very low by virtue of which it gives rise to large eddy current losses when operated at high flux densities in alternating magnetic fields. Pure iron is used in many kinds of electrical apparatus and instruments as magnetic material core for electromagnets, components for relay electrical instruments.

IRON SILICON ALLOYS :

The chief alloying constituent is silicon which is added to iron in amounts from about 0.5 to 5% by weight. Iron-Silicon alloy usually known as Silicon steel. Silicon steel generally used in transformers, electrical rotating machines, reactors, electro magnets and relays.

Silicon sharply increases the electrical resistivity of iron thus decreasing the iron losses due to eddy currents. It increases the permeability at low and moderate flux densities but decreases it at high densities. Addition of silicon to iron reduce the hysteresis loss. The magneto striction effect is reduced.

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

GRAIN ORIENTED SHEET STEEL :

As the ferro magnetic material have a crystal structure. So every crystal of ferro magnetic substance has a particular direction along which it offers high permeability. So it most easily magnetized. Such axes along which the crystals have high permeability and are move easily magnetized are called as easy or soft direction. Along any axis other than the easy direction, the crystal has low permeability and is therefore more difficult to magnetize. Such axes along which the crystal has low permeability are called as hard direction.

For easy magnetization the crystal directions of electrical sheet should be so oriented that their axes are paralled to the direction in which the external magnetic field is applied. This is achieved in practice by carefully controlling the rolling and annealing of silicon iron sheets. The direction of easy magnetization then lie in the direction in which the steel is rolled in the mill. Sheet steel which has been rolled such as to give easy direction to all its crystals is called ‘textured’ or grain oriented steel.

MAGNETIC ANISOTROPY :

The directional dependence of magnetic property under heading grain oriented sheet steel is known as magnetic anisotropy. It is clear that in bulk magnet a great improvement will result if the individual preferred axes are aligned parallel and along the axis of magnetization. A substantial improvement in residual magnetization and coercive force will result from parallel organization of the domain movements. The application of this technology is prevalent in the manufacture of permanent magnet.

ANNEALING :

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

SOFT FERRITES :

Ceramic magnet called as ferro magnetic ceramic and ferrites. Ceramic magnet are made of an iron oxide, Fe_2O_3 with one or more divalent oxides such as NiO, MnO or ZnO. These magnets have a square hysteresis loop and high resistance to demagnetization. The great advantages of territes is their high resistivity. Their resistivity's are as 10^9 Ohm-cm. Ferrites are carefully made by mixing power oxides compacting and sintering at high temperatures. High frequency transformers in television and frequency modulated receivers are almost always made with ferrite core.

HARD MAGNETIC MATERIALS :

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

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

CARBON STEEL, TUNGSTEN STEEL, COBALT STEEL :

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

ALNICO :

It is known as Aluminium-nickel-iron-cobalt. Alnico are commercially the most important of the hard magnetic materials. Large magnets are made by special casting techniques and small one by powder metallurgy. As cobalt steel is cheaper so far this reason permanent magnets are most commonly made of Alnico.

HARD FERRITES :

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

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.

OTHER MATERIALS :

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 185^{o}C 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 316^{o}C 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.