LECTURER NOTES
ON
ELECTRICAL ENGINEERING MATERIAL (EEM)
3RD SEMESTER ELECTRICAL ENGINEERING
SUBJECT CODE-TH4

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Electrical Engineering Material

Conducting materials;

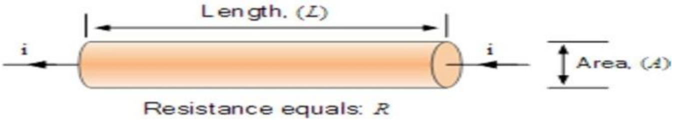
Today's discussion:

- Introduction
- Resistivity
- factors affecting resistivity
- Classification of conducting materials into low-resistivity and high resistivity materials

Resistivity:

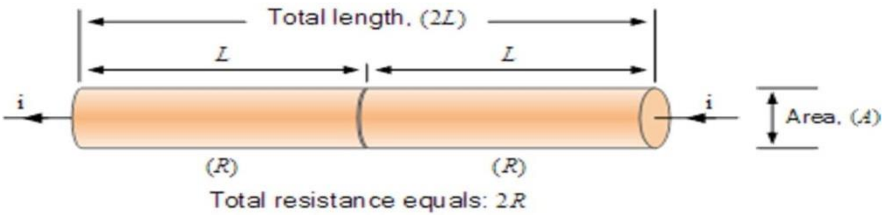
Laws of Resistance:

Let's take a conductor



$$R \propto L$$

(i) The resistance of a substance is directly proportional to the length of the substance. electricalresistance R of a substance is

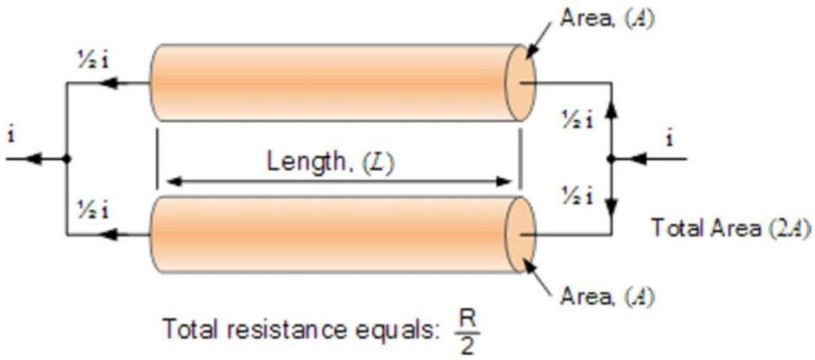


If the length of a substance is increased, the path traveled by the electrons is also increased. If electrons travel long, they collide more and consequently the number of electrons passing through the substance becomes less; hence current through the substance is reduced. In other words, the resistance of the substance increases with increasing length of the substance. This relation is also linear.

(ii) The resistance of a substance is inversely proportional to the cross-sectional area of the substance.

$$R \propto \frac{1}{A}$$

Where A is the cross-sectional area of the substance. The current through any substance depends on the numbers of electrons pass through a cross-section of substance per unit time. So, if the cross section of any substance is larger than more electrons can cross the cross section. Passing of more electrons through a cross-section per unit time causes more current through the substance. For fixed voltage, more current means less electrical resistance and this relation is linear.



(iii) Combining both;

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

Where, ρ (rho) is the proportionality constant and known as **resistivity** or **specific resistance** of the material of the conductor or substance. Now if we put, L = 1 and A = 1 in the equation, we get, R = ρ. That means resistance of a material of unit length having unit cross – sectional area is equal to its **resistivity** or **specific resistance**. Resistivity of a material can alternatively be defined as the electrical resistance between opposite faces of a cube of unit volume of that material.

Unit of Resistivity

The **unit of resistivity** can be easily determined form its equation;

$$R = \rho\frac{L}{A} \Rightarrow \rho = \frac{RA}{L}$$
$$In\ SI\ System\ of\ Unit$$
$$\rho = \frac{R\,\Omega\ \times A\,m^2}{L\,m}$$
$$\Rightarrow \rho = \frac{RA}{L}\quad \frac{\Omega - m^2}{m}\ or\ \Omega - m$$

Factors affecting resistivity:

(a) Temperature
(b) Alloying
(c) Mechanical stress
(d) Age Hardening
(e) Cold Working

(a) Temperature

The resistivity of materials changes with temperature. Resistivity of most of the metals increase with temperature. The change in the resistivity of material with change in temperature is given by formula given below

$$\rho_{t_2} = \rho_{t_1}[1 + \alpha_1(t_2 - t_1)]$$

Where,
ρ_{t1} is the resistivity of material at temperature of t_1 °C and
ρ_{t2} is the resistivity of material at temperature of t_2 °C
α_1 is temperature coefficient of resistance of material at temperature of t_1 °C. If the value of $\alpha 1$ is positive, the resistivity of material is increase.

(b) Alloying

Alloying is a solid solution of two or more metals. Alloying of metals is used to achieve some mechanical and electrical properties. The atomic structure of a solid solution is irregular as compared to pure metals. Due to which the electrical resistivity of the solid solution increases more rapidly with increase of alloy content. A small content of impurity may increase the resistivity metal considerably. Even the impurity of low resistivity increases the resistivity of base metal considerably. For example the impurity of silver (having lowest resistivity among all metals) in copper increase the resistivity of copper.

(c) Mechanical Stressing

Mechanical stressing of the crystal structure of material develops the localized strains in the material crystal structure. These localized stains disturb the movement of free electrons through the material. Which results in an increase in resistivity of the material. Subsequently, annealing, of metal reduces the resistivity of metal. Annealing of metal, relieve the mechanical stressing of material due to which the localized stains got removed from the crystal structure of the metal. Due to which the resistivity of metal decrease. For example, the resistivity of hard drawn copper is more as compared to annealed copper.

(d) Age Hardening

Age hardening is a heat treatment process used to increase the yield strength and to develop the ability in alloys to resist the permanent deformation by external forces. Age hardening is also called “Precipitation Hardening”. This process increases the strength of alloys by creating solid impurities or precipitate. These created solid impurities or precipitate, disturb the crystal structure of metal which interrupts the flow of free electrons through metal/Due to which the resistivity of metal increases.

(e) Cold Working

Cold working is a manufacturing process used to increase the strength of metals. Cold working is also known as “Work hardening” or “Strain hardening”. Cold working is used to increase the mechanical strength of the metal. Cold working disturbs the crystal structure of metals which interfere with the movement of electrons in metal, due to which the resistivity of metal increases.

Classification of conducting materials:

- Low resistivity material
- High resistivity material

<u>Electrical Engineering</u>

<u>Material</u>Conducting materials;

Today's discussion:

1. QUIZ Discussion
2. Low resistivity Material
3. Properties
4. Applications (Ag, Cu, Au, Al, Steel)
5. Stranded Conductor
6. Bundled Conductor
7. Low resistivity Copper alloys

Low resistivity Material

Material having low resistivity or high conductivity are very useful in electrical engineering for manufacturing electrical engineering machines or equipment's. These material used as conductors for all kind of winding required in electrical machines, apparatus and devices. These material are also used as conductor in transmission and distribution of electrical energy.

Required Properties in Low Resistivity or High Conductivity ConductingMaterial

This following properties are required in **high conductivity materials**:

1. Highest possible conductivity (ideally zero).
2. Least possible temperature coefficient of resistance (ideally zero).
3. High melting point.
4. High mechanical strength.
5. High ductility, so that can be drawn in the form of wire easily.
6. High corrosion resistance (free from oxidation).
7. Solder ability, so that can be soldered easily to join the conductors.
8. Low cost.
9. Long life or durable.
10. High flexibility.

The above required properties varies with the purpose for which material is being used. Any impurity whether metallic or non metallic increase the resistivity of metals. Even an impurity of low resistivity will increase the resistivity of metal. The reason behind this is that the addition of slight impurity creates imperfections in the crystal lattice which disturb the flow of electronsthrough metals.

Some of **low resistivity or high conductivity materials** and their resistivity with temperaturecoefficient of resistance are given in table below:-

Sl No.	Metals	Chemical Symbol	Resistivity (μΩ - cm)	Temperature Coefficients of Resistance (/ ^{0}C)
1	Silver	Ag	1.58	0.0038
2	Copper	Cu	1.68	0.00386
3	Gold	Au	2.21	0.0034
4	Aluminium	Al	2.65	0.00429

Silver (Ag)

Silver is the best conductor of electricity. It is having highest conductivity. It is moldable and weld able. The main drawback of it that it is very costly, which limits its practical use in electrical machines / equipment. However, it is still used in precious equipment used for research where cost of equipment does not matter.

Properties:

1. Resistivity : 1.58 μΩ -cm
2. Temperature coefficient of resistance at 20^{o}C: 0.0038/^{o}C
3. Melting point: 962^{o}C
4. Specific gravity: 10.49 gm /cm^3

Copper (Cu)

The extensively used, high conductivity material as conductor for electrical machines or equipment, is copper. Malleability, weld ability and solder ability are most important properties of copper. Copper in pure form is having good conductivity. But the conductivity of standard grade copper is reduced due presence of impurities.

Properties:

1. Resistivity : 1.68 μΩ -cm
2. Temperature coefficient of resistance at 20°C: 0.00386 /°C
3. Melting point: 1085°C
4. Specific gravity: 8.96gm /cm^3

Gold (Au)
Gold is a precious and costly metal. It is having good conductivity. Gold is having highest malleability and ductility among all metals. Due to high cost, its practical use is limited to precious instruments used for research.

Properties:
1. Resistivity : 2.21 μΩ -cm
2. Temperature coefficient of resistance at 20°C: 0.0034 /°C
3. Melting point: 1064°C
4. Specific gravity: 19.30gm /cm^3

Aluminium (Al)
Aluminium is an element which is a silver-white, light weight, soft, non-magnetic and ductile metal. Aluminium is the third most abundant element (after oxygen and silicon) and most abundant metal found in earth's crust. The main ore of aluminium is bauxite. Aluminium is having low density, high ductility, good corrosion resistance and good conductivity, which makes it suitable to use as electric conductor for transmission and distribution of electricity.

Properties:
1. Resistivity: 2.65 μΩ -cm
2. Temperature coefficient of resistance at 20°C: 0.00429 /°C
3. Melting point: 660°C
4. Specific gravity: 2.70 gm /cm^3

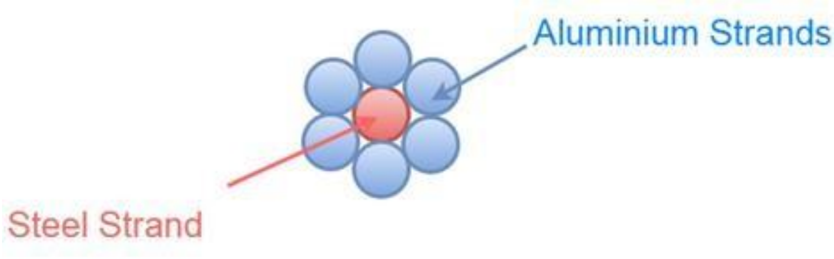
Steel
Steel contains iron with a small amount of carbon added to it. Iron is not that strong but when carbon is added it assumes very good mechanical property, its tensile strength increases, but ductility decreases. Steel is classified as below according to carbon contents,
(i) Mild steel (0.25 % C)
(ii) Medium steel (0.45% of C)
(iii) High Carbon steel (0.7% of C)

Properties:

1. Resistivity: 0.5 μΩ -m
2. Temperature coefficient of resistance at 20°C: 0.00651 /°C
3. Melting point: 1400-1500°C
4. Specific gravity: 7.8 gm /cm^3

Stranded conductors:

Stranded conductors are very much popular in electrical power system for transmission and distribution line. A stranded conductor is consists of several thin wires of small cross sectionalarea called strands as shown in figure below-



Stranded Conductor

As shown in figure above, at the centre of stranded conductor, we are using steel conductor which provided the high tensile strength to conductor. In the outer layers of **stranded conductor**, we use aluminium conductors, which provide the conductivity to stranded conductor.

Basic, reason of using stranded conductor is to make the conductor flexible. If we use a single solid conductor. It does not have sufficient flexibility and it is difficult to coil a solid conductor. Hence, it becomes difficult to transport a single solid conductor of long length over the distance. To eliminate this drawback, conductor is formed by using several thin wires of small cross section. These thin wires are called strands. By making the conductor stranded, it becomes flexible. Which makes **stranded conductor** suitable to be coiled easily to transport itover long distance.

Facts about Stranded Conductor

There are some facts to be noted about stranded conductors:-

1. The **stranded conductor** is having sufficient flexibility, which makes stranded conductor suitable to be coiled easily to transport it over long distance.
2. For a stranded conductor of same cross sectional area, the flexibility of conductorincrease with increase of number of strands in conductor.
3. The stranded conductor is formed by twisting the strands together in layers.
4. The strands of each layer are laid in helical fashion over the preceding

layer. This process is called stranding.

5. clockwise direction, the strands of next layer will be twisted in anticlockwise direction and so on ‘x’ is numberof layers in conductor.
6. Generally, the total number of strands in any conductor is given by the

$$N = 3x^2 - 3x + 1$$

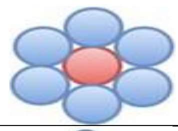
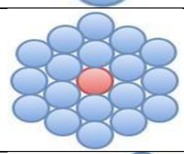
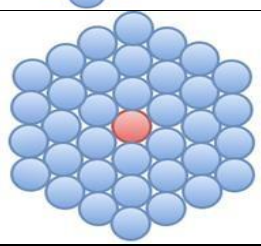
formulae of, Where, N is total number of strands in stranded conductor

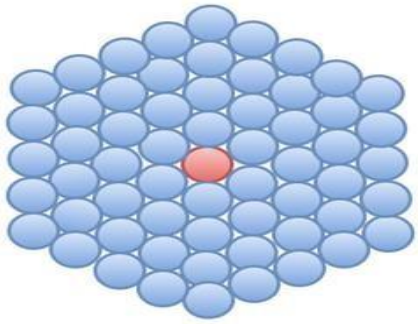
7. Generally the diameter of conductor can be calculated by using the formula of,

Where, D is the diameter of conductor ‘d’ is the diameter of each strand.

$$D = (2x - 1)d$$

Table Representing the Number of Strands, Diameter and Cross-Sectional view ofStranded Conductor for Different no. of Layers

No of layers ‘x’	Total no. of strands N = $3x^2 - 3x + 1$	Diameter of conductor D = $(2x - 1)d$	Cross Sectional View of Stranded Conductor
1	1	d	
2	7	3d	
3	19	5d	
4	37	7d	

5	61	9d	

Bundled Conductor

We call **bundled conductor** to those conductors which form from two or more stranded conductors, bundled together to get more current carrying capacity. Here, we use two or morestranded conductors per phase. Also, to increase the current carrying capacity of the system, a bundle conductor also contributes various facilities to the electrical transmission system. A bundled conductor reduces the reactance of the electric transmission line. It also reduces voltage gradient, corona loss, radio interference, surge impedance of the transmission lines.

Low resistivity Copper Alloys

(a) Brass

When Copper is alloyed with zinc it is called brass. (60% of Cu + 40% of Zn)
It has high tensile strength but low conductivity than Copper. It is solderable & weldable. It has resistance to corrosion. It has wide applications as current carrying and structural material in plug points, socket outlets, switches, lamp holders, sliding contacts of rheostat & starters.

(b) Bronze

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

(c) Beryllium Copper Alloy

The copper alloy containing beryllium is also called Bronze. It bas high conductivity and mechanical strength. Its hardening and elasticity property can be changed by giving appropriate heat treatment. It is used for making current carrying springs, brush holders, coil springs & sliding contacts.

Electrical Engineering Materials

Conducting materials;

Today's discussion:

- QUIZ Discussion
- High resistivity Material
- Properties
- Applications (Tungsten, Carbon, Platinum, Mercury)

High Resistivity or Low Conductivity Conducting Material:-

Materials having high resistivity or low conductivity are very useful for some electrical engineering products and applications. These material are used to manufacture the filaments for incandescent lamp, heating elements for electric heaters and furnaces, space heaters and electric irons etc.

Example:- tungsten, carbon, manganin, nichrome, mercury, platinum

Required Properties in High Resistivity or Low Conductivity Conducting Material:-

The following properties are required in **high resistivity or low conductivity conductingmaterial**–

- High resistivity.
- High melting point.
- High mechanical strength.
- High ductility, so that can be drawn in the form of wire easily.
- High corrosion resistance mean free from oxidation.
- Low cost.
- Long life or durable.
- High flexibility.

Tungsten

Tungsten is produced by very complicated processes from rare ores or from tungstic acids. Some facts about tungsten are listed below-

- Very hard.
- Resistivity is twice to aluminium.
- High tensile strength.
- Can be drawn in the form of very thin wire.
- Oxidize very quickly in the presence of oxygen.

- Can be used up to 2000^{o}C in the atmosphere of inert gases (Nitrogen, Argon etc.) without oxidation.

Properties of Tungsten:

Properties of tungsten are listed below-

- Specific weight : 20 gm/cm^3
- Resistivity : 5.28 µΩ -cm
- Temperature coefficient of resistance : 0.005 /°C.
- Melting point : 3410°C.
- Boiling point : 5900°C.
- Thermal coefficient of expansion: 4.44×10^{-9} /°C.

Uses of Tungsten:

1. Used as filament for incandescent lamp.
2. As electrode in X- ray tubes.
3. The great hardness, high melting and boiling points make it suitable for use as electrical contact material in certain applications. It is having high resistance for destructive forces produces during operation of electrical contacts.

Carbon

Carbon in widely used in electrical engineering. Electrical carbon materials are manufactured from graphite and other forms of carbon.

Properties of Carbon:

1. Resistivity : 1000 – 7000 µΩ – cm
2. Temperature coefficient of resistance : – 0.0002 to – 0.0008 /°C.
3. Melting point : 3500°C.
4. Specific gravity : 2.1gm /cm^3

Uses of Carbon:

Carbon is having following applications in electrical Engineering

1. Used for making pressure sensitive resistors, which are used in automatic voltageregulators.
2. Used for manufacturing the carbon brushes, which are used in DC machines. These carbon brushes improve the commutation as well as reduce the wear and tear.
3. For making filament of incandescent lamp.
4. For making electrical contacts.
5. For making resistors.

6. For making battery cell elements.

7. Carbon electrodes for electric furnaces.
8. Arc lighting and welding electrodes.
9. Component for vacuum valves and tubes.
10. For makings parts for telecommunication equipment.

Manganin

Composition of Manganin:-

$$Cu = 84\ \% \ + \ Mn = 12\ \% \ + \ Ni \ = 4\ \%$$

Properties of Manganin:

1. Resistivity : 40 μΩ -cm
2. Temperature coefficient of resistance : 0.0001 /°C.
3. Melting point : 1400°C.
4. Specific gravity : 8.4gm /cm^3
5. High resistance to oxidation

Uses of Manganin:

Manganin is having following applications in Electrical Engineering.

1. Used in making electric heating elements and in electric furnaces.
2. As the manganin is having very low temperature coefficient of resistance, therefore it is used to make the standard resistances and in measuring instruments.

Platinum:

Properties:

1. Platinum is greyish white metal which is non-corroding. It is malleable and ductile andis resistant to most chemicals.

2. Platinum is a heavy metal having:-

3. specific weight of 21.4 gm/cm^2

4. melting point is 1775°C.

5. resistivity is 0.1 x 10^{-6} ohm metre

6. temperature coefficient is 0.00307 per degree C.

7. Platinum can be drawn into thin wires and strips.

8. It does not oxidize in air and has no tendency to arc.

Uses of Platinum:

1. Platinum finds application as a heating element in laboratory ovens and The furnaces. Platinum-rhodium thermocouple is used for measurement of temperature up to 1600°C.
2. Platinum is also used as electrical contact material and as material for grids in special purpose vacuum tubes.
3. An important application platinum is as material for contacts. Materials used for making contacts have to withstand arcing and space-over whenever contacts are separated. When materials are used for this purpose they may have to operate under very severe conditions particularly when they are subjected to frequent make and break operations.
   Hence they deteriorate with time are because of
   a. corrosion
   b. erosion

(Corrosion is the oxide form in material when they are exposed to water & atmosphere. Generally, it can be avoided by high contact to contact pressure which will break up oxide films.)

(Erosion is caused by fusing & wearing of the working surface of the contact during any operation. It will cause growth to appear on any contact & cavity in other.)

Mercury

Properties:

1. Mercury is a heavy silver white metal having
2. Specific weight is 13.55 gm/cm².
3. boiling point is 357°C
4. Resistivity is 0.95×10^{-6} ohm-metre
5. Temperature coefficient is $0.00027/^{o}C$
6. It is the only metal which is liquid at room temperature.
7. Mercury is poisonous.

Uses of Mercury:

In the field of electrical engineering mercury finds application in

1. mercury arc rectifiers,
2. gas filled tubes,
3. liquid contact material in electrical switches.
4. An important example of mercury being used for making and breaking contact isBuchholz relay used for transformer protection.

Electrical Engineering Material

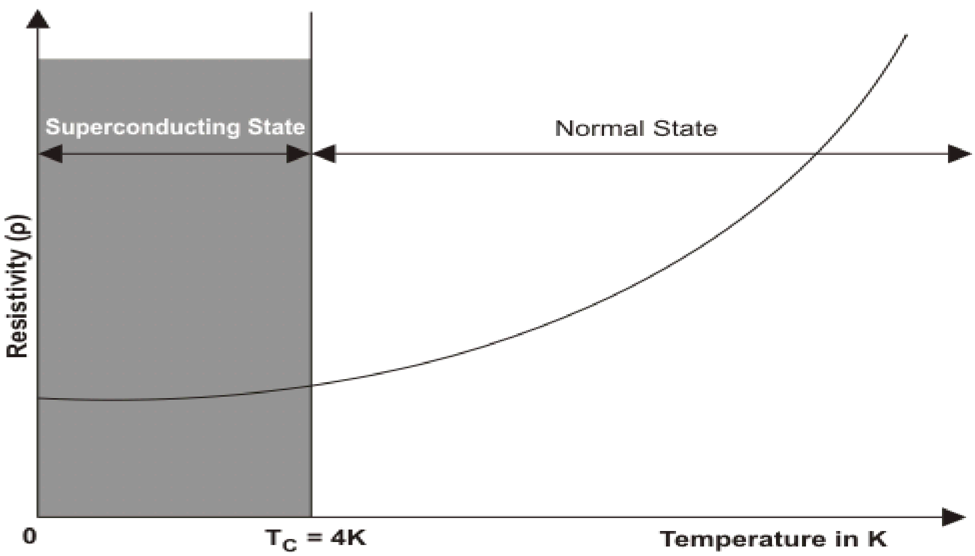
Conducting materials;

Today's discussion:

- QUIZ Discussion
- SUPERCONDUCTIVITY
- Super conducting materials
- Applications

Superconductivity was discovered by Dutch Physicist Heike Kamerlingh Onnes in 1911 in Leiden. He was awarded the Nobel Prize in Physics in 1913 for his low-temperature research.Some materials when they are cooled, below certain temperature their resistivity get abolished means they exhibit the infinite conductivity.

The temperature, at which the metals change from normal conducting state to superconductingstate, is called critical temperature/transition temperature. An example of superconductors, is Mercury. It becomes superconductor at 4k. In superconducting state the materials expel the magnetic field. A transition curve for mercury is shown in figure below-



The transition from normal conducting state to superconducting state is reversible. Moreover, below critical temperature the superconductivity can be abolished either by passing sufficient large current through conductor itself or by applying sufficient strong external magnetic field. Below critical temperature/transition temperature, the value of current through conductor itself at which the superconducting state abolished is called critical current. As the temperature (below the critical temperature) reduces the value of critical current increase. The value of critical current increase with decrease in temperature. The value of critical magnetic field also depends on temperature. As the temperature (below the critical temperature) reduces the value of critical magnetic field increase.

Superconductor Metals:

Some metals when they are cooled below their critical temperature exhibits the zero resistivity or infinite conductivity. These metal are called superconductor metals. Some metals showing superconductivity and their critical temperatures/transition temperature are listed in table below:-

SL	Superconductor	Chemical Symbol	Critical/Transition Temperature T_C(K)
1	Rhodium	Rh	0
2	Tungsten	W	0.015
3	Beryllium	Be	0.026
4	Iridium	Ir	0.1
5	Lutetium	Lu	0.1
6	Hafnium	Hf	0.1
7	Ruthenium	Ru	0.5
8	Osmium	Os	0.7
9	Molybdenum	M	0.92

		o	
10	Zirconium	Zr	0.54 6
11	Cadmium	Cd	0.56
12	Uranium	U	0.2
13	Titanium	Ti	0.39
14	Zinc	Zn	0.85
15	Gallium	Ga	1.08 3
16	Gadolinium	Gd	1.1
17	Aluminium	Al	1.2
18	Protactinium	Pa	1.4
19	Thorium	Th	1.4
20	Rhenium	Re	1.4
21	Thallium	Tl	2.39
22	Indium	In	3.40 8
23	Tin	Sn	3.72 2
24	Mercury	Hg	4.15 3
25	Tantalum	Ta	4.47
26	Vanadium	V	5.38
27	Lanthanum	La	6.0
28	Lead	Pb	7.19 3

Applications of Superconductivity

In modern field of technology the superconductivity is widely used in different fields oftechnology. Some of these applications are listed below-

1. Medical: MRI (Magnetic Resonance Imaging), Ultra-Low Field Magnetic Resonance Imaging (ULF-MRI), Magneto-encephalography (MEG) and Magnetic Source Imaging(MSI), Magneto-cardiography (MCG) etc.

2. Electrical field: Generators, motors, transformers, relays, magnetic energy storages (SMES), superconducting magnets, HTS Induction Heater, Fusion etc.

3. Electronics: SQUIDS (superconducting quantum interference device), High Speed computing, Quantum computing, Sensors, filters, circuitry, radar etc.

4. Transportation: Magnetically levitated trains, Marine Propulsion (magneto-hydrodynamic), Marine Propulsion (motor) etc.

5. Physics: Particle Accelerators, Magnets, Plasma / fusion research etc.

Electrical Engineering Material

Semiconductors;

Today's discussion:

Semiconductors
Electron Energy
Energy and Theory
Insulators, Semiconductors and Conductors

Conductors:

a) **Conductors** are materials that have very low values of resistivity, usually in the micro-ohms per metre. This low value allows them to easily pass an electrical current due to there being plenty of free electrons floating about within their basic atom structure. utthese electrons will only flow through a conductor if there is something to spur their movement, and that something is an electrical voltage.

b) When a positive voltage potential is applied to the material these "free electrons" leave their parent atom and travel together through the material forming an electron drift, more commonly known as a current. How "freely" these electrons can move through aconductor depends on how easily they can break free from their constituent atoms when a voltage is applied. Then the amount of electrons that flow depends on the amount of resistivity the conductor has.

c) Examples of good conductors are generally metals such as Copper, Aluminium, Silveror non-metals such as Carbon because these materials have very few electrons in their outer " alence Shell" or ring, resulting in them being easily knocked out of the atom's orbit. This allows them to flow freely through the material until they oin up with otheratoms.

d) generally speaking, most metals are good conductors of electricity, as they have very small resistance values, usually in the region of micro-ohms per metre (.m).

e) While metals such as copper and aluminium are very good conducts of electricity, theystill have some resistance to the flow of electrons and consequently do not conduct perfectly.

f) The energy which is lost in the process of passing an electrical current, appears in the form of heat which is why conductors and especially resistors become hot as the resistivity of conductors increases with ambient temperature.

insulators

a) **insulators** on the other hand are the exact opposite of conductors. They are made of materials, generally non-metals, that have very few or no “free electrons” floating aboutwithin their basic atom structure because the electrons in the outer valence shell are strongly attracted by the positively charged inner nucleus.

b) In other words, the electrons are stuck to the parent atom and cannot move around freelyso if a potential voltage is applied to the material no current will flow as there are no“free electrons” available to move and which gives these materials their insulatingproperties.

c) Insulators also have very high resistances, millions of ohms per metre, and are generally not affected by normal temperature changes (although at very high temperatures wood becomes charcoal and changes from an insulator to a conductor). Examples of good insulators are marble, fused quartz, P C plastics, rubber etc.

d) Insulators play a very important role within electrical and electronic circuits, because without them electrical circuits would short together and not work. For example, insulators made of glass or porcelain are used for insulating and supporting overhead transmission cables while epoxy-glass resin materials are used to make printed circuit boards.

Semiconductors:

a) **Semiconductors** materials such as silicon (Si), germanium (e) and gallium arsenide (aAs), have electrical properties somewhere in the middle, between those of a “conductor” and an “insulator”. They are not good conductors nor good insulators (hence their name “semi”-conductors). They have very few “free electrons” because their atoms are closely grouped together in a crystalline pattern called a “crystal lattice” but electrons are still able to flow, but only under special conditions.

b) The ability of semiconductors to conduct electricity can be greatly improved byreplacing or adding certain donor or acceptor atoms to this crystalline structure thereby,producing more free electrons than holes or vice versa. That is by adding a small percentage of another element to the base material, either silicon or germanium.

Electron Energy

The energy of an electron is of the same order of magnitude (is in the same range) as the energyof light. The lines in the spectrum of an element represent changes in the energy of electrons within the atoms of that element.

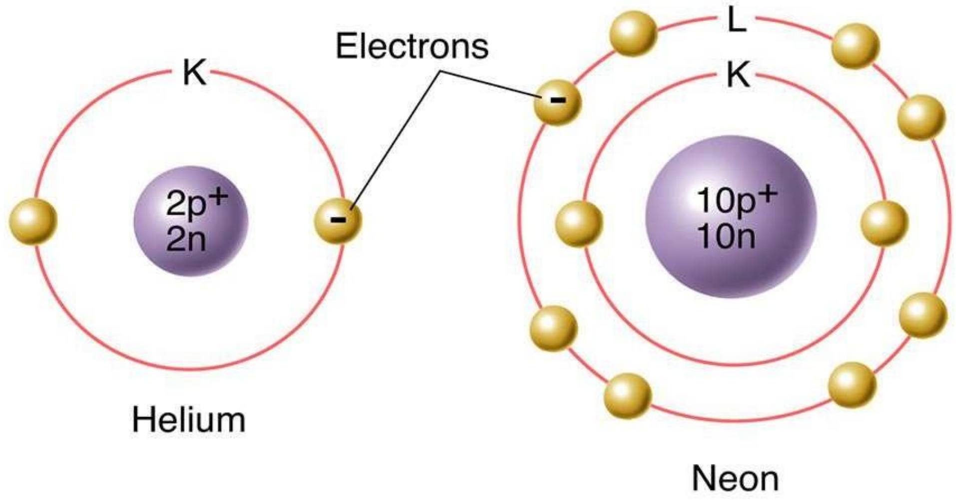
1. The energy of an electron depends on its location with respect to the nucleus of an atom. The higher the energy of an electron in an atom, the farther is its most probable location from the nucleus. Notice that we say **probable location**. Because of the electron s small size and high energy, we are limited in how precisely we can mark its position at any instant. We can only describe regions around the atom s nucleus within which the electron may be found.

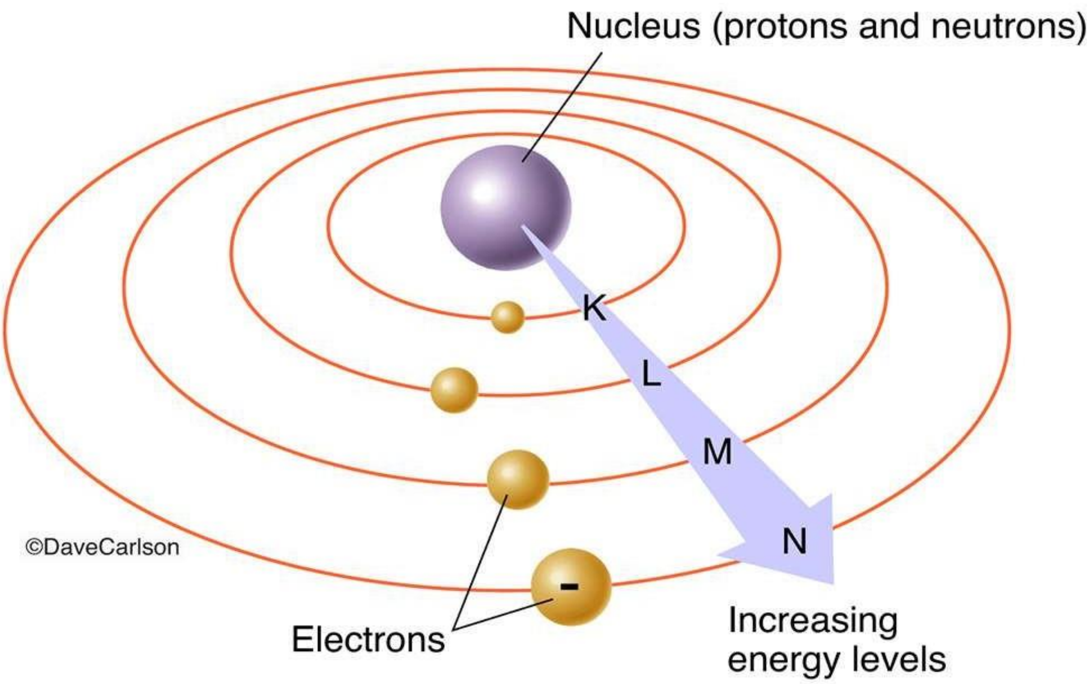
2. In describing these regions of space, we also recognize that the energy of an electron is quantized

Electron V O L T (e)

An electron revolving around the nucleus of an atom has potential energy, centrifugal energy, rotational energy magnetic energy. All of which together determine the total energy or the energy level of the electrons. This value is measured in electron volts, expressed as e .

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





Energy and Theory:

a) According to ohr's theory, each and every shell and subshell of atoms contain a discrete amount of energy. An atom has different energy levels. When atoms are brought closer to each other, electrons at outermost shell interact with each other. This bonding force between electrons is called as an inter-atomic interaction.

b) This interaction causes the change in energy levels of electrons at the outermost shell. This change will give rise to energy band theory, and hence electrons will not be at the same level, the levels of the electrons are changed to a value which is higher or lower than that of the original level.

c) Each substance consists different amount of electron energy present in the energy bands, based on these different energy levels. Energy band are then further classified as:

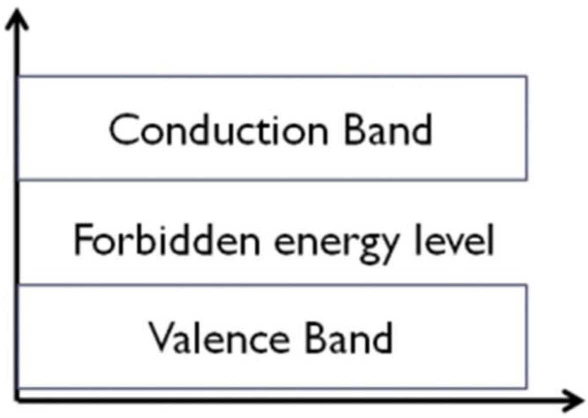
alence band

Forbidden

Energy Gap

Conduction Band

These and can be explained as



valence band:

a) At absolute zero temperature, there are the different range of energies present in the solid and the band which is formed by the highest range of energy is called valence band this band is filled with valence electrons.

b) valence band can also be explained as, when atoms are brought closer together to form a solid, the discrete energy levels are disturbed because of quantum mechanical effects, and many electrons in the group of the individual atom occupy a band of levels in the solid, this band of levels called as valence band. This band is formed by the electrons at an outermost shell.

c) It is located below the Fermi level. Electrons in the valence band have lower energy than the electrons in the conduction band. In atoms, the electrons present in the valence band is loosely bound to the nucleus. The electrical conductivity of a solid depends on the capability to move the electrons from the valence band to the conduction band.

forbidden Energy Level:

a) Forbidden energy gap is also known as Fermi energy level. It is the electronic energy band where there is no electron state exists due to quantization energy. The band obtained by separating conduction band and valence band is called as forbidden energyband or forbidden gap.

In solids, the electrons do not stay in forbidden gap as there is no energy state in this region. With the help of forbidden gap, we can determine the ma or factor, i.e., the electrical conductivity of the solid

Condu ction and:

a) The energy band formed by the energy levels of the free electrons is called conduction band. The conduction band is an empty band or partially filled band, but when the external field is applied to the electrons in the valence band, the electrons ump from the valence band to the conduction band and becomes free electron.

b) Electrons in the conduction band have higher energy than the electrons in the valence band. In the conduction band electrons are not bound to the nucleus of the atom.

c) Conduction band can also be defined as empty states which are broadened into a band of levels. This band is placed above the Fermi level. It is the lowest range of vacant electronic state.

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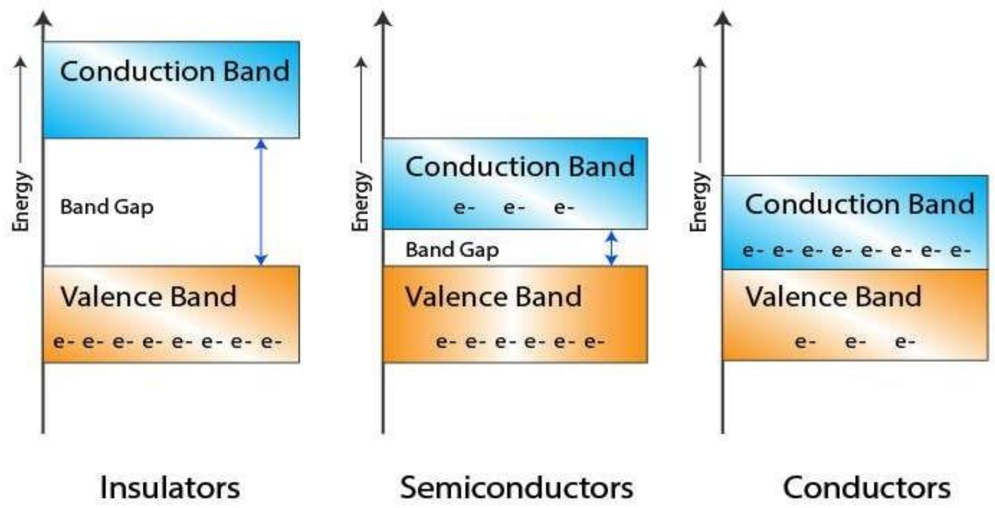
So accordingly:



Electrical Engineering Material

Semiconductors;

- ***Excitation of atoms***
- ***Semiconductor materials***
- ***Covalent bonds***
- ***Intrinsic Semiconductors***
- ***Extrinsic Semiconductors***

E citations of Atoms:

(a) When each electron in an atom is in its normal orbit, we call it as unexcited state. To movean electron further away from the nucleus, extra energy is required.

(b) Excitation of atoms can be done in following methods.

- **Light**
- **Heat**
- **Electrostatic**
- **Magnetic**
- **inetic**

(c) So when a required amount of energy will be provided, an atom will leave lower state and will go to a higher energy state.

(d) The required energy to move an atom from one state to another state, varies from material to material. If in one material, an atom needs 1.9eV, the in another it will take 3.5eV.

(e) By applying light, heat, electro static source a valence electron can be moved from its unexcited state to ionization state. At this stage, all attractive force from the nucleus is leased & the electron will be in between atom & conduction stage. This electron is known as **free electron** & the atom is known as **positively ioni s ed atom**.

(f) If by any means, the free electron will not be used in chemical reaction or movement for conduction, it will lose that extra energy and it will again come back to the atom to make it neutral again.

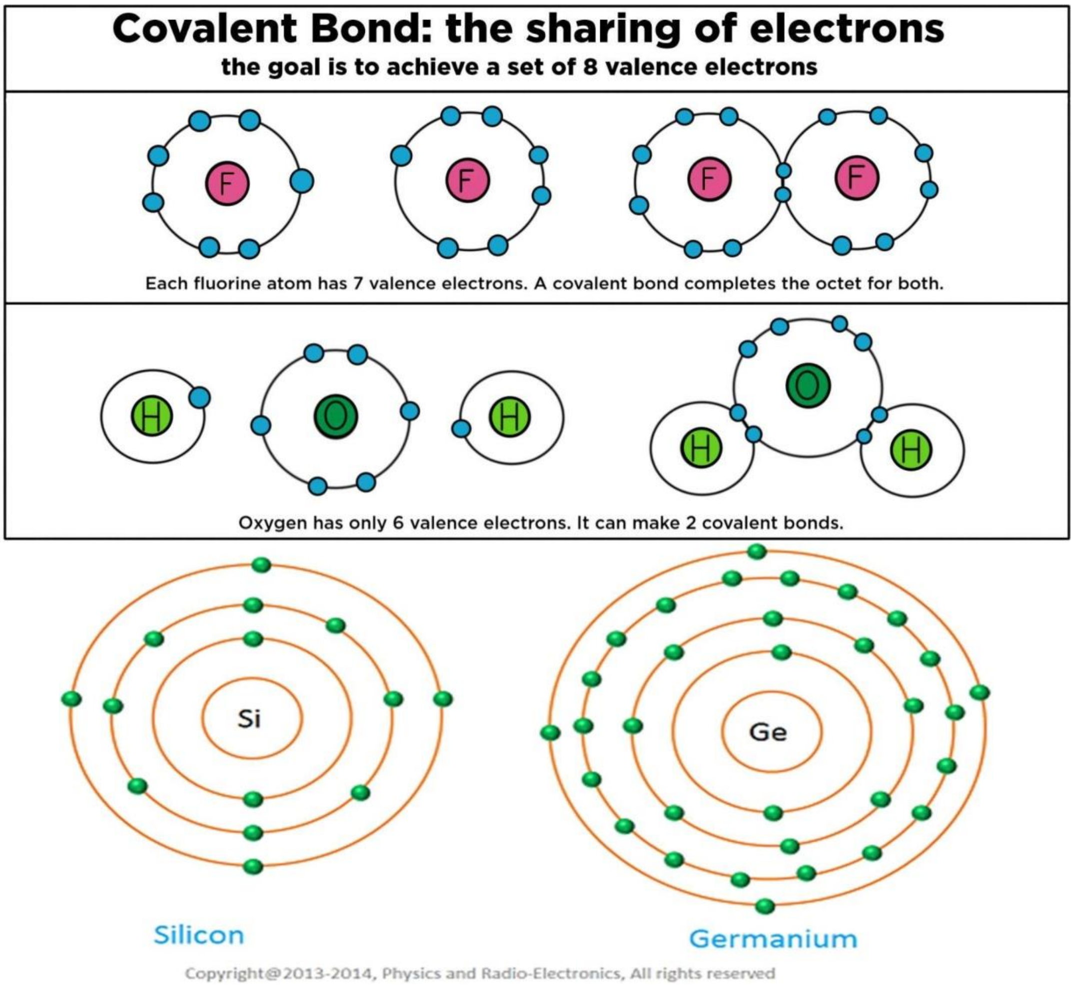
Semiconductor Materials:

a) The electrical characteristic of semiconductor comes between conductor & insulator. Thus it will obviously possess a valence ring of FOUR rather than EIGHT electrons forbest insulator & 1-2 electrons for the best conductor.
b) The best two material used for semiconductor are silicon (Si) & germanium

(Ge).

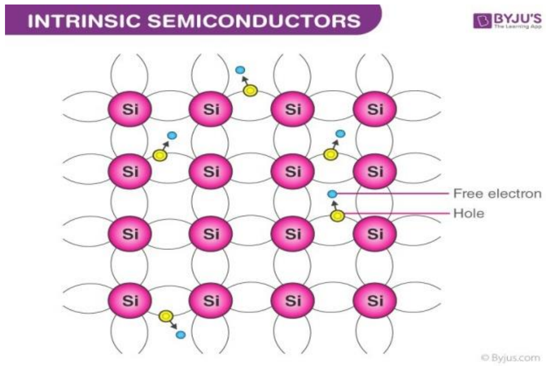
c) In Si, K & L shells are full but M contains only four electrons. According to $2n^2$ formula, it should have 18 electrons, but as it is the outer most shell, it should not contain more than 8 electrons.

d) Similarly in Ge, K,L,M are full but N has 4 electrons in outer most shell.



Covalent b o n d

A covalent bond results when each atom, in order to fill its valence ring with 8 electrons, share electrons with neighbour atoms. This sharing of electrons is known as covalent bonds.



Ideally material having 8 electrons in outer shell must be act as inert or refuse to do any kind of chemical reaction. This should be the best quality for an insulator. As in insulator we don't want the electrons to come out of the valence shell & help in conduction. But this doesn't happen. Because:

I. Insulator must have a perfect crystal structure. But in covalent bond, the structure is notcrystal, it has so many individual crystals in imperfect manner. The extra atoms are notproperly locked in place and there are missing atoms in some parts of the structure.
II. Due to impurities there may be extra electrons which cannot lock into the covalent bond structure. Impurities also be the reason why electrons are missing in a structure.

III. Outside energy like heat, light, electro static source can harm the structure.

The above reasons lead the material to become imperfect insulator. Fortunately this helps to discover a good semiconductor.

Semiconductor material can be classified as

- √ Intrinsic semiconductor
- √ Extrinsic semiconductor

Intrinsic semiconductor:

Semiconductors that are chemically pure, in other words, free from impurities are termed as intrinsic semiconductors. The number of holes and electrons is therefore determined by the properties of the material itself instead of the impurities. In intrinsic semiconductors, the number of excited electrons is equal to the number of holes; $n = p$. They are also termed as undoped semiconductors or i-type semiconductors. Silicon and germanium are examples

We notice from the electron configurations of both the elements that they have four electrons in their outermost shell or valence shell. As the temperature of the semiconductor is increased, the electrons gain more thermal energy and thus break free from their shell. The process of ionization of the atoms in the crystal lattice creates a vacancy in the bond between the atoms. The position from which the electron gets dislodged has a hole which is equivalent to an effective positive charge. The hole is then occupied by a free electron, as a result of which the latter vacant position becomes a hole and the former becomes a neutral position. This way the hole or the effective positive charge is transferred from one position to another. In an intrinsic semiconductor, the number of free electrons is equal to the number of holes.

When the temperature of an intrinsic semiconductor is T=0K, it behaves like an insulator. When the temperature is increased further, (T>0), the electrons get excited and move from the valence band to the conduction band. These electrons occupy the conduction band partially, leaving a correspondingly equal number of holes in the valence band.

E X trinsic semiconductor:

Extrinsic semiconductors are semiconductors that are doped with specific impurities. The impurity modifies the electrical properties of the semiconductor and makes it more suitable forelectronic devices such as diodes and transistors.

While adding impurities, a small amount of suitable impurity is added to pure material, increasing its conductivity by many times.

. The process of adding impurities deliberately is termed as and the atoms that are used as an impurity are termed as . Theimpurity modifies the electrical properties of the semiconductor and makes it more suitable forelectronic devices such as diodes and transistors.

The dopant added to the material is chosen such that the original lattice of the pure semiconductor is not distorted. Also, the dopants occupy only a few of the sites in the crystal of the original semiconductor and it is necessary that the size of the dopant is nearly equal to the size of the semiconductor atoms.

Electrical Engineering Material

Semiconductors;

Today's discussion:

- **Minority & Majority charge carrier**
- **P-type semiconductor**
- **N-type semiconductor**

Holes and Electrons in Semiconductors

Holes and electrons are the types of charge carriers accountable for the flow of current in semiconductors. **Holes** (valence electrons) are the positively charged electric charge carrier whereas **electrons** are the negatively charged particles. Both electrons and holes are equal in magnitude butopposite in polarity.

Mobility of Electrons and Holes

In a semiconductor, the **mobility of electrons is higher than that of the holes**. It is mainly because of their different band structures and scattering mechanisms.

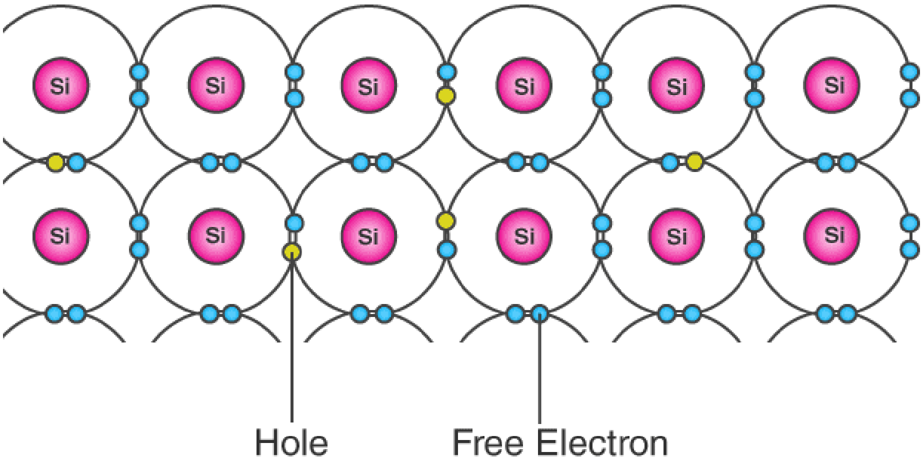
Electrons travel in the conduction band whereas holes travel in the valence band. When an electric field is applied, holes cannot move as freely as electrons due to their restricted movement. The elevation of electrons from their inner shells to higher shells results in the creation of holes in semiconductors. Since the holes experience stronger atomic force by the nucleus than electrons, holes have lower mobility.

The mobility of a particle in a semiconductor is more if;

- Effective mass of particles is lesser
- Time between scattering events is more

For intrinsic silicon at 300 K, the mobility of electrons is 1500 $cm^2 (V\cdot s)^{-1}$ and the mobility of holes is 475 $cm^2 (V\cdot s)^{-1}$.

The **bond model** of electrons in silicon of valency 4 is shown below. Here, when one of the free electrons (blue dots) leaves the lattice position, it creates a hole (grey dots). This hole thus created takes the opposite charge of the electron and can be imagined as positive charge carriers moving in the lattice.



Concept of Electrons and Holes in Semiconductors

Band Theory of Semiconductors

The introduction of band theory happened during the quantum revolution in science. Walter Heitler and FritzLondon discovered the energy bands.

We know that the electrons in an atom are present in different energy level. When we try to assemble a lattice of a solid with N atoms, then each level of an atom must split up into N levels in the solid. This splitting up of sharp and tightly packed energy levels forms **Energy Bands**. The gap between adjacent bands representing a range of energies that possess no electron is called a **Band Gap**.

Conduction Band and Valence Band in Semiconductors

Valence Band:

The energy band involving the energy levels of valence electrons is known as the valence band. It is the highest occupied energy band. When compared with insulators, the band gap in semiconductors is smaller. It allows the electrons in the valence band to jump into the conduction band on receiving any external energy.

Conduction Band:

It is the lowest unoccupied band that includes the energy levels of positive (holes) or negative (free electrons) charge carriers. It has conducting electrons resulting in the flow of current. The conduction band possess high energy level and are generally empty. The conduction band in semiconductors accepts the electrons from the valence band.

What is Fermi Level in Semiconductors?

Fermi level (denoted by EF) is present between the valence and conduction bands. It is the highest occupied molecular orbital at absolute zero. The charge carriers in this state have their own quantum states and generally do not interact with each other. When the temperature rises above absolute zero, these charge carriers will begin to occupy states above Fermi level.

In a **p-type semiconductor**, there is an increase in the density of unfilled states. Thus, accommodating more electrons at the lower energy levels. However, in an **n-type semiconductor**, the density of states increases, therefore, accommodating more electrons at higher energy levels.

Properties of Semiconductors

Semiconductors can conduct electricity under preferable conditions or circumstances. This unique property makes it an excellent material to conduct electricity in a controlled manner as required.

Unlike conductors, the charge carriers in semiconductors arise only because of external energy (thermal agitation). It causes a certain number of valence electrons to cross the energy gap and jump into the conduction band, leaving an equal amount of unoccupied energy states, i.e. holes. Conduction due to electrons and holes are equally important.

- **Resistivity:** 10^{-5} to 10^{6} Ωm
- **Conductivity:** 10^{5} to 10^{-6} mho/m
- **Temperature coefficient of resistance:** Negative
- **Current Flow:** Due to electrons and holes

Why does the Resistivity of Semiconductors go down with Temperature?

The difference in resistivity between conductors and semiconductors is due to their difference in charge carrier density.

The resistivity of semiconductors decreases with temperature because the number of charge carriers increases rapidly with increase in temperature, making the fractional change i.e. the temperature coefficient negative.

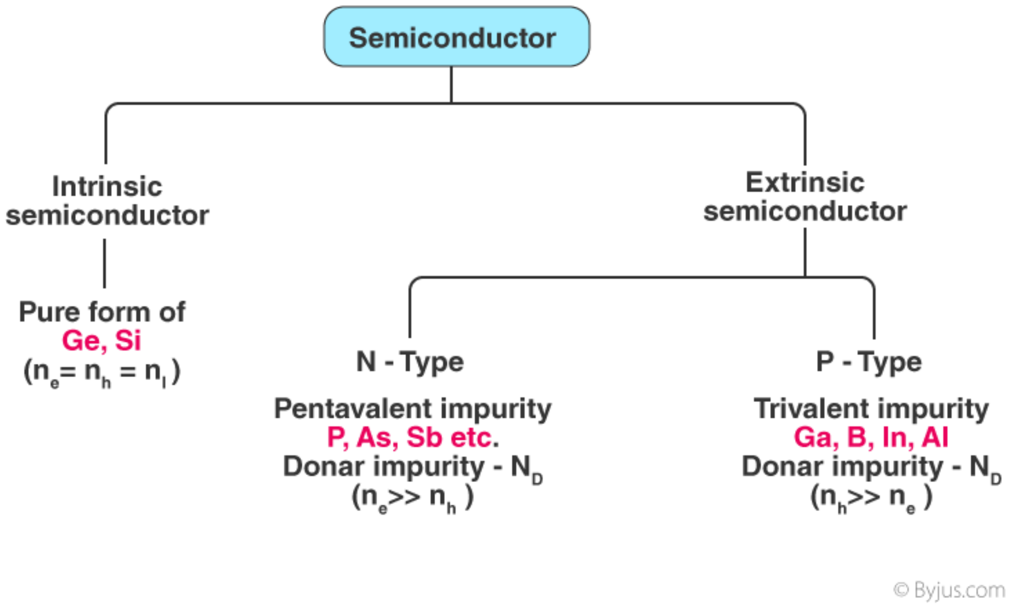
Some Important Properties of Semiconductors are:

1. Semiconductor acts like an insulator at Zero Kelvin. On increasing the temperature, it works as a conductor.
2. Due to their exceptional electrical properties, semiconductors can be modified by doping to make semiconductor devices suitable for energy conversion, switches, and amplifiers.
3. Lesser power losses.
4. Semiconductors are smaller in size and possess less weight.
5. Their resistivity is higher than conductors but lesser than insulators.
6. The resistance of semiconductor materials decreases with the increase in temperature and vice-versa.

Types of Semiconductors

Semiconductors can be classified as:

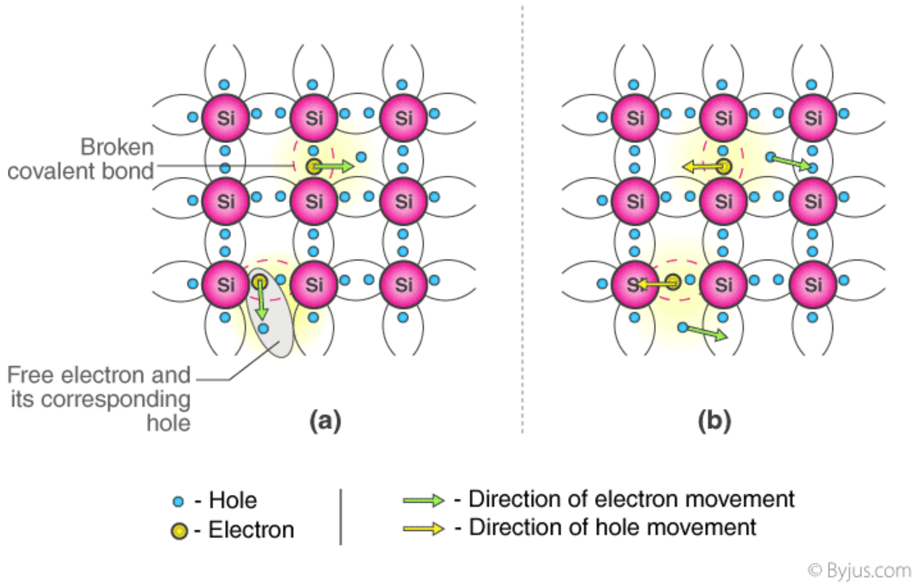
- **Intrinsic Semiconductor**
- **Extrinsic Semiconductor**



Classification of Semiconductors

Intrinsic Semiconductor

An **intrinsic type of semiconductor material** is made to be very pure chemically. It is made up of only a single type of element.



Conduction Mechanism in Case of Intrinsic Semiconductors (a) In absence of electric field (b) In presence of electric Field

Germanium (Ge) and Silicon (Si) are the most common type of intrinsic semiconductor elements. They have four valence electrons (tetravalent). They are bound to the atom by covalent bond at absolute zero temperature.

When the temperature rises, due to collisions, few electrons are unbounded and become free to move through the lattice, thus creating an absence in its original position (hole). These free electrons and holes contribute to the conduction of electricity in the semiconductor. The negative and positive charge carriers are equal innumber.

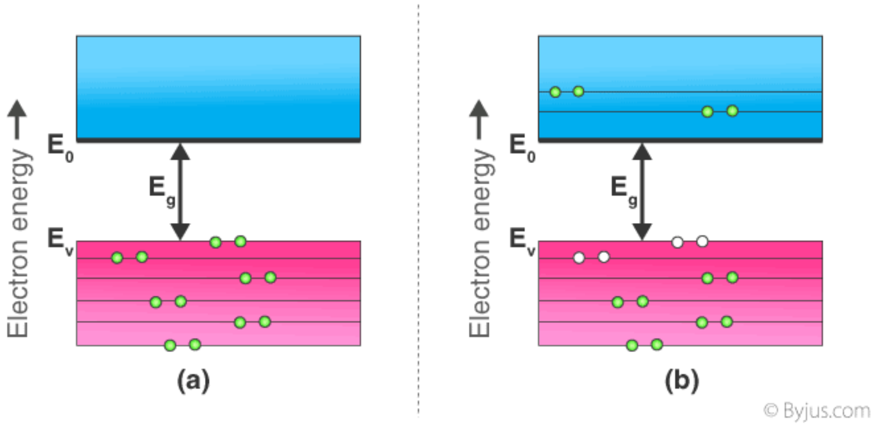
The thermal energy is capable of ionizing a few atoms in the lattice, and hence their conductivity is less.

The Lattice of Pure Silicon Semiconductor at Different Temperatures

- **At absolute zero kelvin temperature:** At this temperature, the covalent bonds are very strong andthere are no free electrons and the semiconductor behaves as a perfect insulator.
- **Above absolute temperature:** With the increase in temperature few valence electrons jump intothe conduction band and hence it behaves like a poor conductor.

Energy Band Diagram of Intrinsic Semiconductor

The energy band diagram of an intrinsic semiconductor is shown below:



(a) Intrinsic Semiconductor at T = 0 Kelvin, behaves like an insulator (b) At t>0, four thermallygenerated electron pairs

In intrinsic semiconductors, current flows due to the motion of free electrons as well as holes. The total current is the sum of the electron current I_e due to thermally generated electrons and the hole current I_h

Total Current (I) = $I_e + I_h$

For an intrinsic semiconductor, at finite temperature, the probability of electrons to exist in conduction band decreases exponentially with increasing bandgap (Eg)

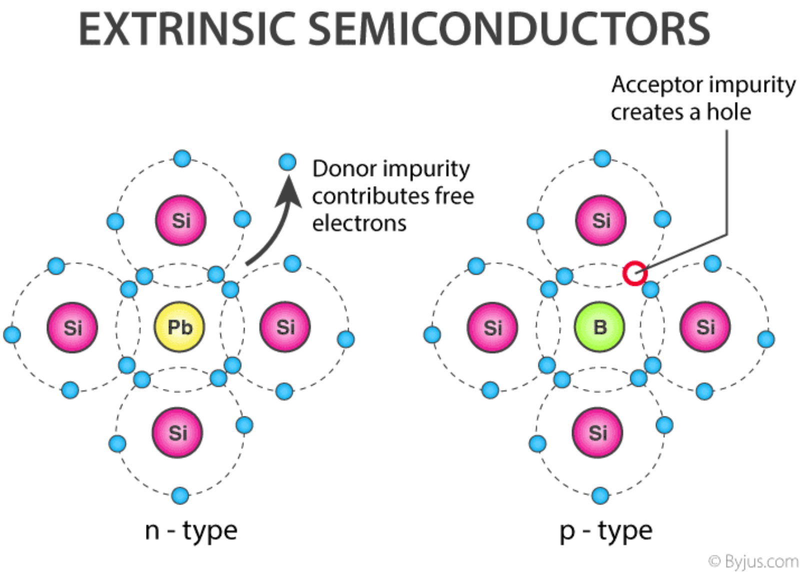
$$n = n_0 e^{-E_g/2.K_b.T}$$

Where,

- Eg = Energy bandgap
- K_b = Boltzmann's constants

Extrinsic Semiconductor

The conductivity of semiconductors can be greatly improved by introducing a small number of suitable replacement atoms called IMPURITIES. The process of adding impurity atoms to the pure semiconductor is called DOPING. Usually, only 1 atom in 10^7 is replaced by a dopant atom in the doped semiconductor. An extrinsic semiconductor can be further classified into:



N-Type Semiconductor

- Mainly due to electrons
- Entirely neutral
- $I = I_h$ and $n_h >> n_e$
- Majority – Electrons and Minority – Holes

When a pure semiconductor (Silicon or Germanium) is doped by pentavalent impurity (P, As, Sb, Bi) then, four electrons out of five valence electrons bonds with the four electrons of Ge or Si.

The fifth electron of the dopant is set free. Thus the impurity atom donates a free electron for conduction in the lattice and is called "**Donar**".

Since the number of free electron increases by the addition of an impurity, the negative charge carriers increase. Hence it is called n-type semiconductor.

Crystal as a whole is neutral, but the donor atom becomes an immobile positive ion. As conduction is due to a large number of free electrons, the electrons in the n-type semiconductor are the MAJORITY CARRIERS and holes are the MINORITY CARRIERS.

P-Type Semiconductor

- Mainly due to holes
- Entirely neutral
- $I = I_h$ and $n_h >> n_e$
- Majority – Holes and Minority – Electrons

When a pure semiconductor is doped with a trivalent impurity (B, Al, In, Ga) then, the three valence electrons of the impurity bonds with three of the four valence electrons of the semiconductor.

This leaves an absence of electron (hole) in the impurity. These impurity atoms which are ready to accept bonded electrons are called "**Acceptors**".

With the increase in the number of impurities, holes (the positive charge carriers) are increased. Hence, it is called p-type semiconductor.

Crystal as a whole is neutral, but the acceptors become an immobile negative ion. As conduction is due to a large number of holes, the holes in the p-type semiconductor are MAJORITY CARRIERS and electrons are MINORITY CARRIERS.

Difference between Intrinsic and Extrinsic Semiconductors

Intrinsic Semiconductor	**Extrinsic Semiconductor**
Pure semiconductor	Impure semiconductor
Density of electrons is equal to the density of holes	Density of electrons is not equal to the density of holes
Electrical conductivity is low	Electrical conductivity is high
Dependence on temperature only	Dependence on temperature as well as on the amount of impurity
No impurities	**Trivalent impurity, pentavalent impurity**

Applications of Semiconductors

Let us now understand the uses of semiconductors in daily life. Semiconductors are used in almost all electronic devices. Without them, our life would be much different.

Their reliability, compactness, low cost and controlled conduction of electricity make them ideal to be used for various purposes in a wide range of components and devices. transistors, diodes, photo sensors, microcontrollers, integrated chips and much more are made up of semiconductors.

Uses of Semiconductors in Everyday life

- Temperature sensors are made with semiconductor devices.
- They are used in 3D printing machines
- Used in microchips and self-driving cars
- Used in calculators, solar plates, computers and other electronic devices.
- Transistor and MOSFET used as a switch in Electrical Circuits are manufactured using thesemiconductors.

Industrial Uses of Semiconductors

The physical and chemical properties of semiconductors make them capable of designing technological wonders like microchips, transistors, LEDs, solar cells, etc.

The microprocessor used for controlling the operation of space vehicles, trains, robots, etc is made up of transistors and other controlling devices which are manufactured by semiconductor materials.

Importance of Semiconductors

Here we have discussed some advantages of semiconductors which makes them highly useful everywhere.

- They are highly portable due to the smaller size
- They require less input power
- Semiconductor devices are shockproof
- They have a longer lifespan
- They are noise-free while operating

Electrical Engineering Material

Semiconductors;

Today s discussion:

Applications of Semiconductor materials:-

Rectifiers
Temperature-sensitive resisters or thermistorsPhotoconductive cells
Photovoltaic cells
varisters
Transistors
Hall effect generators Solar power

Advantages of using Si:

a) The main advantages of semiconductors based on the Si are;
b) long life cycle,
c) small volume,
d) light weight,
e) simple production,
f) great mechanical strength,
g) low supplying power,
h) economical production

Rectifiers:

a) P-type N-type materials are oined together to form a unction called the P-N unction. When external voltage is applied across the two materials a flow of current results if the positive and negative terminals of the voltage source are connected respectively to the extreme ends of the P- and N-type materials.

b) voltage applied in this way is called forward biasing the P-N unction. If the applied voltage is reversed i.e. the positive of the supply voltage is connected to the N side and the negative of the supply voltage is connected to the P side, there is no flow of current.This is called reverse biasing. So the P-N unction offers high conductivity when forward biased and no conductivity when reverse biased.

c) Thus semiconductors can be used as rectifiers. Semiconductor P-N unction diodes have almost replaced thermionic values as rectifiers. Modern P-N unction rectifiers use germanium or silicon as the semiconductor material.

Why Si is chose ahead of germanium

I. germanium rectifiers were invented earlier than silicon rectifiers. It is easier and simpler to produce germanium mono-crystals. ermanium has a melting point of Cand silicon 1, 1 C. Molten silicon combines readily with practically all chemical elements and, is therefore, very difficult to purify and maintain free from impurity. All this would favour the use of germanium.

II. However, owing to vital economic and technological advantages especially in heavy current application silicon rectifiers find wider industrial application. The Germanium and Silicon semiconductors find wide use in both high frequency and supply frequencycircuits particularly as non-controlled rectifiers let e.g. diodes and controlled rectifiers (e.g. transistors and silicon controlled rectifiers).

d) A silicon controlled rectifier (SCR) may be considered as a combination of two transistors one n-p-n type and the other p-n-p type. The regenerative or, action of the device depends on the current gain of the two separate transistors. The sum of the current gains of the two transistors should approach unity for this. Since e does not exhibit such property, only Si is used as base material for developing Silicon Controlled Rectifiers (SCRs) of Silicon rectifiers are available for very high PI rating, of the order of 2 k and current rating of the order of 1 amps. out frequency response is poor (i.e. at high frequency the depletion capacitance becomes prominent and this causes distortion of the rectified wave shape). Silicon rectifiers are normally used in power rectifying devices.

Temperature sensitive Resisters or Thermisters:

a) Increasing the temperature of semiconductor materials causes their resistance to decrease. This property has found application in devices called thermisters.

b) Thermisters are thermally sensitive resistors. They are made from oxides of certain metals such as copper, manganese, cobalt, iron, zinc. ften a mixture of several oxidesis used because it can be arranged to give them the required properties.

c) Thermisters find application in temperature measurement and control. They sense temperature variations and convert these variations into an electrical signal which is then used to control heating devices. ther applications of thermisters include measurement of radio frequency, power, voltage regulation and timing and delay circuits.

photoconductive Cells:

The resistance of semiconductor material is low under light and increases in darkness. This phenomenon in used in photoconductive cells where a semiconductor material is connected in series with voltage source. The resistance of the semiconductor varies with the intensity of light and thus the current in the circuit is controlled. Photoconductive cells can be seen in applications which require the control of s certain function or event according to the colour or intensity of light. Some of their applications are those of door openers, burglar alarms, flame detectors, smoke detectors and control for street lights.

photovoltaic Cells:

Photovoltaic cells are devices that develop an emf when illuminated. Thus they convert light energy directly into electrical energy. No outside source of electrical energy is required to produce current flow as a photoconductive device.

varisters:

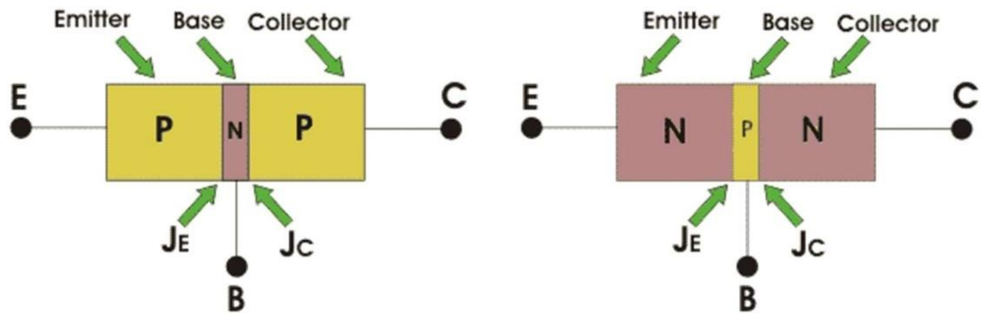
The resistance of semiconductors varies with the applied voltage. This property is used indevices called varisters.se of varisters are made in voltage stabilizers and motor speed control.

Transistors:

a) The resistance of semiconductors depends to a large extent on the magnitude of electric field. The current in a semiconductor does not follow hms law and increases for morerapidly than the voltage.

b) This property has been used in the device called transistor. A transistor is a two unction three terminal device, the two unctions being formed by oining P, N and P material orN, P and N materials as shown in figure.

c) Transistors have replaced the vacuum and gas tubes in performing many obs includingamplification of signals and switching circuits.



Hall Effect generators:

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

b) Consider the semiconductor bar shown in figure, which has contacts on all four sides. If a voltage EF is applied across the two opposite contacts A and , a current will flow. If the bar is placed perpendicular to a magnetic field , as shown in the figure, electric potential EH is generated between the other two contacts C and D. This voltage EH is a direct measure of the magnetic field strength and can be detected with a simple voltmeter.

c) The hall effect generator may be used to measure magnetic fields. It is capable of measuring magnetic field strengths that have a strength 1 - of the magnetic field of the earth.

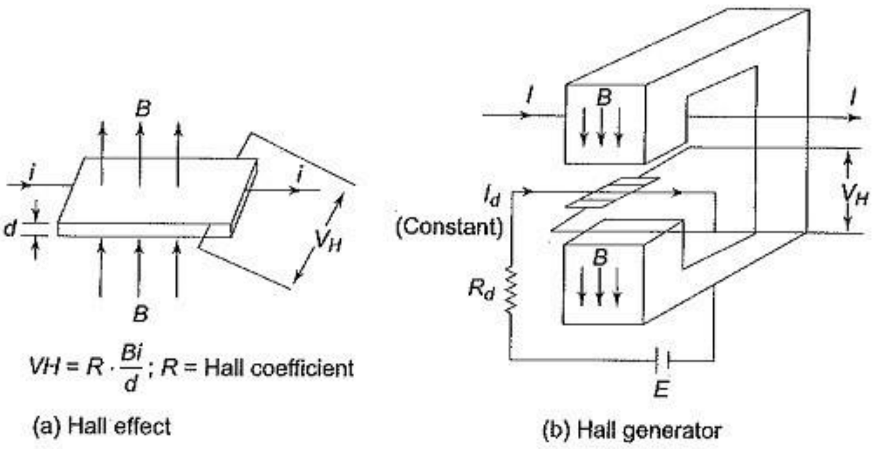


Fig. 7.44 *Hall generator for measuring high d.c. currents*

Solar power:

a) Sun is a vast source of energy. There have been lot of research work in the recent years, as a result of which many practical devices have been developed which are in operationtoday.

b) ne of its important applications is the conversion of solar power into electrical power. This phenomenon is called the photo voltaic effect. Solar cell is the most important photovoltaic device which directly converts the solo radiations (light energy) into electrical energy.

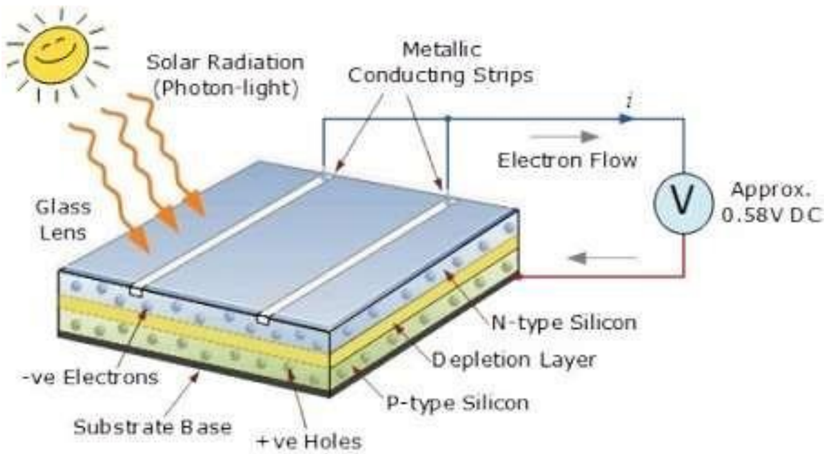
c) Solar cell is basically a thin disc of P-N unction with a large surface area. A very thin layer of P-type material of the order of few microns is diffused on the upper surface of the disc to form a shallow p-n unction. This is then enclosed in a glass container with the top surface filled with silicon grease to prevent losses by reflection.

d) When light rays fall on the surface of this arrangement electrons start flowing from n- plate to the p-plate by means of the photoemission process. This gives rise to a potentialdifference and constitutes flow of an electric current.

e) The output depends on the intensity of the sun ray. As the cell turned away from the sun, the output decreases approximately as the cosine of the angle of incidence. The rise in temperature causes a sharp fall in conversion efficiency. The optimum temperature for getting a steady state conversion about ^{o}C.

f) The presence of moisture or carbon dioxide in the atmosphere affects adversely to the performance of a solar cell. The overall efficiency of a solar cell is 1 -12 . The total voltage or current required can be increased by series/parallel connections of solar cells thus developing solar batteries popularly known as tank.

g) Applications of solar cells are small power source such as in watches, calculators, telephones in rural areas, solar water heater, solar pump, space research work etc.



Merits of Semiconductor material in Electrical field:

1. They are much smaller in size and light in weight.
2. When used as rectifiers and transistors they do not require a heater or filament as isrequired in electron tube rectifiers and valves.

. They consume low power resulting in high efficiency.

. They have long life and hardly show ageing effects.

. They are almost shock proof.
. They operate on low voltage.

CH-3: INSULATING MATERIAL

Introduction:

a) An insulator is a material that does not conduct electrical current. Insulating materials include paper, plastic, rubber, glass and air. Vacuum is also an insulator, but is not actually a material.
b) Most electrical conductors are covered by insulation. Magnet wire is coated with an extremely thin layer of insulation so that more turns or larger wire may be used in the winding of transformers etc.
c) Insulators are generally rated at hundreds of volts, but some that are used in power distribution are rated as high as hundreds of thousands of volts. Insulators support and or keep electrical conductors from making unintended contact with each other.

Definition:

What is an Electrical insulator

a) An **electrical insulator** (also referred to as an insulator) is used in an electrical system to prevent unwanted flow of current to the earth from its supporting points. The **insulator** plays a vital role in the electrical system. An electrical insulator is a very high resistive path through which practically no current can flow.

b) In transmission and distribution systems, the overhead conductors are generally supported by supporting towers or poles. The towers and poles both are properly grounded. So there must be an insulator between tower or pole body and current- carrying conductors to prevent the flow of current from conductor to earth through the grounded supporting towers or poles.

Does Insulator is always reliable

The main cause of failure of the overhead line insulator is flashover, which occurs between line and earth during abnormal overvoltage in the system. During this flashover, the huge heat produced by arcing causes puncher in the insulator body. Viewing this phenomenon the materials used for electrical insulator has to possess some specific properties.

General Properties of Insulators:

The materials generally used for the insulating purpose is called insulating material. For successful utilization, this material should have some specific properties as listed below.

1. It must be mechanically strong enough to carry the tension and weight of conductors.
2. It must have a very high dielectric strength to withstand the voltage stresses in HighVoltage transmission systems.
3. It must possess high Insulation Resistance to prevent leakage current to the earth.
4. The insulating material must be free from unwanted impurities.
5. It should not be porous.

. There must not be any entrance on the surface of the electrical insulator so that the moisture or gases can enter it.

. There physical as well as electrical properties must be less effected by changing temperature.

Classification of Properties:

1. Electrical properties
2. Visual properties
3. Mechanical properties
4. Thermal properties
5. chemical properties

. Ageing

Electrical Properties:

A. Insulation Resistance:-
insulation resistance-is the property, by the virtue of which, a material resists flow of electrical current. It should be high as possible. Insulation resistance is of two types:

Volume resistance

Surface resistance.

The resistance offered to the current, which flows through the material iscalled **volume resistance**

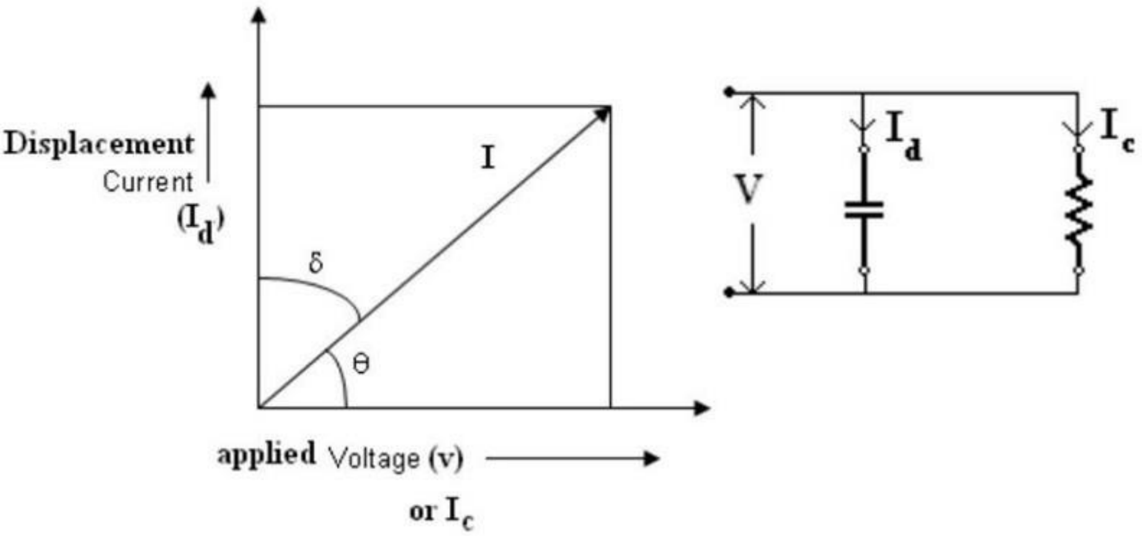
The resistance offered to the current, which flows over the surface of the insulating material is called **surface resistance**. Factors that affect the insulation resistance are- temperature variations, exposure to moisture, voltage applied, aging.

B. D**ielectric Strength** is therefore the minimum voltage which when applied to an insulating material will result in the destruction of its insulating properties. It can also be defined as the maximum potential gradient that the material can withstand without rupture, or without loosing dielectric properties. This value is expressed in volts or kilovolts per unit thickness of the insulating material. This value is greatly affected by the conditions under which the material is operated. Factors affecting the dielectric strength are temperature and humidity.

.**Dielectric Constant** Every insulating material has got the basic property of storing charge ( ), when a voltage (V) is applied across it. The charge is proportional to the voltage applied i.e. V, or = V. Where is called the capacity or capacitance of the material across which the voltage is applied. Every insulating material behaves as a capacitor. apacitance is different for different insulating material. The property of insulating materials that causes the difference in the value of capacitance, with the physical dimensions remaining the same is called dielectric constant or permittivity ( )and = o, where is capacity in presence of Dielectric and o is the capacity in air or vacuum or in the absence of dielectric.

Dielectric loss and Loss angle: When a perfect insulation is sub ected to alternating voltage, it is like applying alternate voltage to a perfect capacitor. In a perfect capacitor the charging current would lead the applied voltage by 90^0 exactly. This means that there is no power loss in the insulation. In most insulating materials this is not the case. There is a definite amount of dissipation of energy when an insulator is sub ected to alternating voltage. This dissipation of energy is called dielectric loss. Factors affecting dielectric loss are - Frequency of applied voltage, humidity, temperature rise and voltage.

The dielectric phase angle is and = 90^0 - is the dielectric loss angle as shown in the fig. below.



Also I is the phasor sum of Id and Ic , where Ic is the conduction current which is in phase with the applied voltage and Id is the displacement current which is in quadraturephase with applied voltage.

Visual roperties:

A Appearance
Colour
C Crystallinity

These properties are not of any significant importance from engineering point of view. But these factors like appearances, colour, smooth to surface count to some extent towards the customer selection.

Mechanical P roperties:

The properties affecting the selection of later are many but we shall consider only those which are of comparatively great importance.

a **Mechanical Strength:** Most solid insulators have to withstand various loads during manufacture as well as during operation when used in an equipment. Strength requirement is very basic although the magnitude may differ for different applications.

The mechanical strength of insulating materials depends upon a number of factors given below

(1) **Temperature rise**: Temperature rises as a result of heat generation in the conductor and the dielectric loss in the insulator. High temperatures can adversely affect the mechanical strength of insulating materials. When selecting insulating materials, this factor should be kept in view and where high temperatures are involved an appropriate insulating material capable of withstanding this should be chosen.
(2) **Climatic effects**: Humidity can also adversely affect mechanical strength of insulating materials. Therefore, non-hygroscopic materials should be selected where necessary. Insulating materials are likely to be sub ected to various types of mechanical stresses i.e: **tension compression resistance to abrasion tear shear and impact**. What type is going to be important will depend on the specific application.

b V**iscosity:** Viscosity in liquid dielectrics will affect manufacturing processes. For example, in paper insulated cable the temperature at which the oil will penetrate through paper will depend on its viscosity. The method to be used to purify the insulating oil used in transformers and other applications will depend upon theviscosity of the oil.

c P**orosity:** High porosity insulating materials will increase the moisture holding capacity and consequently adversely affect electrical properties. Therefore normally itis not desired to have a dielectric of high porosity. However, in certain applications porosity is advantageous and is therfore desirable as for example when paper is to be impregnated with oil.

d **Solubility:** In certain applications insulation can be applied only after it is dissolved in some solvent. In such cases the insulating material should be soluble in certain appropriate solvents. An insulation should not dissolve and he washed out in fluids it comes in contact with during operations. If the insulating material is soluble in water then moisture in the atmosphere will always be able to remove the applied insulation and cause break down.

e **Machinability and Mouldability:** These properties are important from the point of view of economic mass production.

Thermal Properties:

It is already mentioned that one of the ma or functions of insulation is heat transfer. Consider an underground cable under operation. This cable is recommended for operation with certain limitations of voltage and current. Suppose voltage is increased. If the involved insulating material is able to withstand the higher voltage stress, the change
will cause increase of dielectric losses that will increase heat generation.

Ultimately the temperature of the insulation will further increase. If the insulator starts losing its insulating properties, ultimately breakdown will occur. Secondly, if load current in the cable is increased, I^2R losses will increase, resulting once again in increased heat generation and failure as mentioned. This example signifies that in an apparatus heattransfer function decides:

The voltage rating and up to what safe limit the voltage can be raised and forhow much period without break down;
Loading and overloading current limitation;
Ambient temperature and maximum temperature an insulation can withstand.

Temperature affects such diverse and important properties as electrical properties, mechanical strength, hardness, viscosity, solubility etc. This makes thermal properties very important. It will now be appreciated why a complete classification of insulating materials on the basis of their operating temperatures has been done. Various thermal properties are discussed below

1. **Melting points lash oints olatility:** Melting point assumes importance in specific cases like non-draining compound impregnated paper insulated cable etc. It is desired that in the entire operating temperature range of

cables the impregnating compound must not melt to avoid migration of oil. Flash point will impose restriction in manufacturing processes to avoid possible hazards of apparatus catching fire. Volatility assumes importance from the fact that when a trapped gas is evolved from a volatile insulating material sub ected to voltage stress, the break-down is very rapid. A volatile material cannot be a good insulator.

2. **Thermal Conductivity:** Heat generated due to I^2R losses and dielectric losses will be dissipated through the insulator itself. How effectively this flow of heat takes place, depends on the thermal conductivity of the insulator. An insulator with better thermal conductivity will not allow temperature rise because of effective heat transfer through it to the atmosphere. This property assumes grout importance in high voltage apparatus where thickness of insulation is more.

3. **Thermal Expansion:** An insulator with a high coefficient of expansion possess problems. Repented load cycles of an apparatus cause corresponding expansion and contraction of the insulator lending to the possibility of the formation of voids in it. When there are two insulating materials involved to form an insulation system different coefficients of expansion of the two will further increase the formation of voids. Those voids have been found to be the ma or cause insulation breakdown.

4. **Heat Resistance:** This is a general property which desires that, dielectric should withstand temperature variation within desirable limits, without damaging its other important properties. If an insulator has favourable properties at ambient temperature but is not able to retain these properties to desirable extent at higher temperature but is not able to retain these properties to desirable extent at higher temperatures up to which it has to operate, it is not a good insulator. On the contrary an insulator which is capable of withstanding high, temperatures without deterioration of its other properties can be used for operation for such higher temperatures. This means that the current loading can be increased thus making the apparatus capable of handling more power. This favours economy.

5. **Classification of insulating Materials on the basis of operating Temperatures:** In view of the important part played by the thermal properties mentioned above it is obvious why the classification of dielectrics is made on the basis of operating temperatures.

. **Effect of Temperature increase on Life of insulator:** There is always some recommended operating temperature for an insulator. The operating temperature has a bearing on the life of the concerned apparatus. A thumb rule suggested by many experts is that life of insulation is halved for each 8 to 10 rise above the recommended operating temperature for a given apparatus.

Chemical properties:

Chemical Resistance: p resence of gases, water, acids, alkalis and salts affects different insulators differently. hemically a material is a better insulator if it resists chemical action. certain plastics are found approaching that condition. onsequently their use is very such on the increase. lastics have replaced paper insulation in many applications because of the former being chemically inert and hygroscopic. However, chemical resistance requirements of insulations used in underground cables which are likely to operate under severe chemical condition due to water, salt, acids or alkalis will be more demanding than those of the insulations used in motor winding. In high voltage installations "Ozone-resistance assumes great importance because of richness of Ozone in the s rounding atmosphere produced by the ionization of air.

Hygroscopicity: Many insulators come in contact with atmosphere here either during manufacture or operation or both. The contact of insulation atmosphere is often so complete that even the less chemically aggressive atmosphere can prove a threat to the smooth running of apparatus. Moisture due to high humidity atmosphere can affect insulators in two ways:

It acts on the surface of insulation.
It may be absorbed by the insulation.

Moisture thus absorbed affects all the electrical properties adversely. However there are insulating materials like paraffins, polythene, polytetra-flouroethylen (TFE) whichare non-hygroscopic.

Effect of Contact with ther Materials: Insulation remains invariably in contact with different types of materials like air, gases, moisture, conducting materials and structural materials. Unlike gases and moisture whose effect on insulation has already been considered, the conducting and structural materials have little effect due to contact with the insulation. There are some cases as rubber in contact with copper, where chemical action takes place. To avoid this chemical action a coating of tin is applied tou before putting a rubber insulation. Ionisation is also come in contact with structural material as for example, in an oil filled capacitor. In capacitor using synthetic insulation oil, the oil react with the inner walls of the tank causing iron particles to mix with the oil. This can adversely affect the insulating property of oil.

Ageing:

Ageing is a long time

effect ofHeat,
hemical action,
Voltage
application.

These factors decide the natural life of an insulation and thus of an apparatus.

CLASSIFICATION

- **Fibrous Material**
- **Impregnated fibrous material**
- **Non-resinous material**
- **Insulating liquids**
- **Ceramics**
- **Mica & Mica products**
- **Asbestos & its products**
- **Glass**
- **Natural & Synthetic rubbers**
- **Insulating resins & their products**
- **Laminates, Adhesive, Enamels & varnishes**

Fibrous materials:

They are derived from animal origin or from cellulose, which is the major solid constituent of vegetable plants. The majority of materials are from cellulose. This includes paper, wood, card- board, cotton, jute and silk.

Impregnated fibrous material:

The fibrous materials are impregnated with suitable impregnated oil, varnish, and epoxy - resin to improve its thermal, chemical and hygroscopic properties.

Non-resinous materials:

Solid or semisolid insulations which are directly available in nature and are organic based come under this class. These materials are mineral waxes, asphalts, bitumen and chlorinated naphthalene.

Insulating liquids:

Apart from working as insulation, they fulfil other important requirements like they offer good heat dissipation media, they used for extinguishing arcs in certain applications like circuit breakers. They include vegetable oils, fluorinated liquids, mineral insulating oils and synthetic liquids.

Ceramics:

They are materials made by high temperature firing treatment of natural clay and certain inorganic matters. They are used as dielectric in capacitors, as insulatorsetc.

Mica and mica products:

It is an inorganic mineral and one of the best natural insulating materials available. Mica is used as a dielectric in capacitors, as insulator. Some of the mica products are glass- bonded mica, synthetic mica, mica paper, manufacturedmica.

Asbestos and asbestos products:

These are strong and flexible fibres. It finds extensive use in electrical equipment as insulation because of its ability to withstand very high temperatures. Some of the asbestos products are: asbestos roving, asbestos paper, asbestos tapes and asbestos cement.

Glass:

Glass is an inorganic material made by the fusion of different metallic oxides. It is normally transparent, brittle and hard. Glass finds its use in electrical industry because of its low dielectric loss, slow ageing and good mechanical strength. Glass is used in electrical-bushings, fuse bodies, insulators, radio and televisiontubes.

Natural and synthetic rubber:

Natural rubber is obtained from the milky sap of rubber trees. It finds limited applications because it is rigid when solid, sticky when warm and gets oxidised, when exposed to atmosphere. Synthetic rubber are of various types such as butadiene rubber, butyl rubber, chloroprene and silicon rubber which are obtained by the polymerisation. Synthetic rubber, are used as insulating material for wires and cables. It is also used as jacketing material for cables.

Insulating resins and their products:

Plastic or resins are of two types - one derived from plant and animals the other synthetic obtained from chemical reactions. Natural resins are used as binder material. It is used as thickening agent for manufacture of mineral insulating oils. Synthetic resins are used as insulation, manufacture of switches and instrument mountings, electrical bushings, radio and television cabinets etc.

Laminates, adhesives, enamels and varnishes:

Laminates are multiple, thin layers or sheets of insulating materials like that of mica, paper, cloth, glass etc bonded together. Adhesives, is a class of material compositions required to carry out bonding between two or more solid surfaces. Adhesives are used in the manufacture of laminated boards, coil winding cylinders, rods, tubes and special shaped insulators. Enamel is a fusible insulated coating of some organic base material, which is generally applied on conducting surface. Enamel finds extensive use in coating wires used for the windings of low rated motors, transformers, various types of instruments, etc. Varnish is a liquid, which when applied to a surface dries resulting in hard shining coating which is resistant to air and water. Lacquer is used for protecting wood and metal surface from external weather conditions.

DIELECTRIC MATERIAL- CH-4

INTRODUCTION

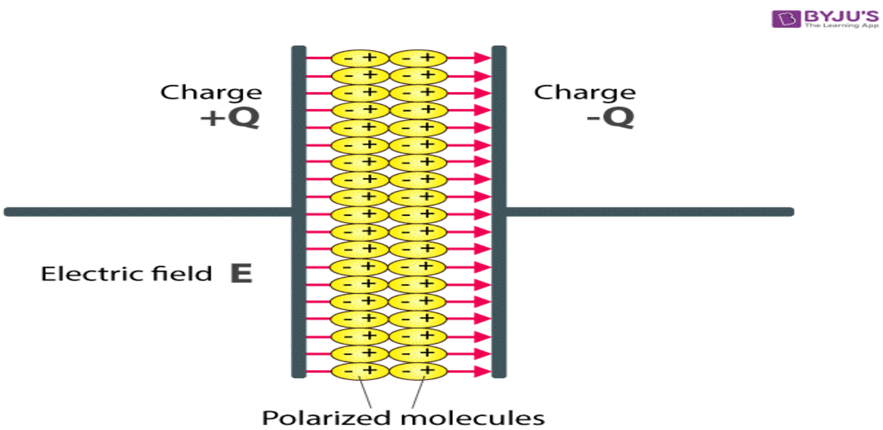
A dielectric material is a non-metallic substance having a high specific resistance, a negative temperature coefficient of resistance and a high insulating resistance. Another definition of dielectric material is a non-conducting substance that holds electrical charges.

Dielectric characteristics

When a dielectric is placed in an electric field, the electric charges do not flow through the material. Electric charges slightly shift from their average equilibrium positions, causing dielectric polarisation.

Dielectric polarisation causes positive charges to flow in the direction of the field and negative charges to shift in the opposite direction of the field. This phenomenon yields an internal electric field, which in turn reduces the overall electric field within the dielectric material.

Electric susceptibility gives the measure of how easily a dielectric material can be polarized when placed in an electric field.



Above figure explains the polarisation of dielectric molecules when the electric field is applied.

Dielectric materials are mostly solids. The dielectrics are mostly solids. Some of the dielectrics are composed of weakly bonded molecules. In such scenarios, along with polarisation, we can also observe that molecules reorient themselves to align their symmetry axes with the field.

Dielectric materials are used to store energy. These materials exist in solid, liquid and gaseous forms. Some examples of dielectric materials are:

- **Solid Dielectrics** – Ceramic, Plastic, Mica, and Glass.
- **Dielectric Liquid** – Distilled Water.
- **Dielectric Gas** – Dry Air, vacuum, nitrogen and helium.

Properties of Dielectric Material

Following are the exhibits of dielectric materials:

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

What Is Dielectric Constant?

The dielectric constant of a substance can be defined as:

The ratio of the permittivity of the substance to the permittivity of the free space
It expresses the extent to which a material can hold electric flux in it.

Dielectric Constant Formula

It is mathematically expressed as:

K=E/E0
Where,

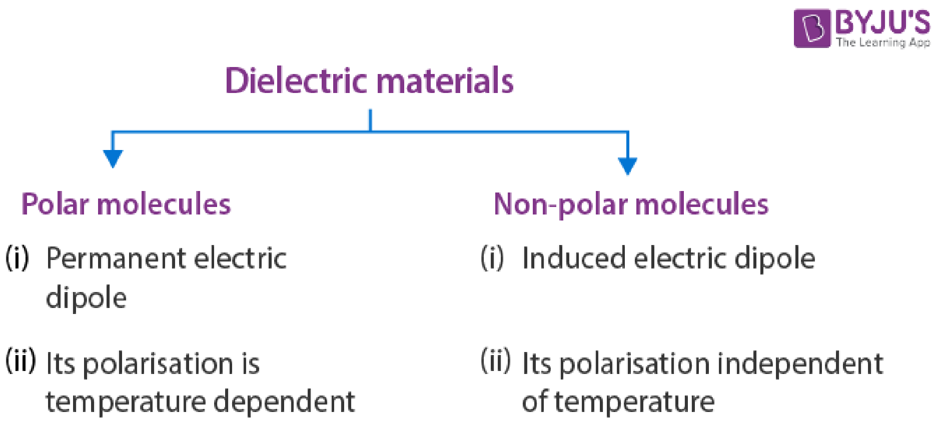
- κ is the dielectric constant
- ε is the permittivity of the substance
- ε_0 is the permittivity of the free space

Dielectric Constant Units

As it is the ratio of two like entities, it is a unit less, dimensionless quantity.

Dielectric Materials

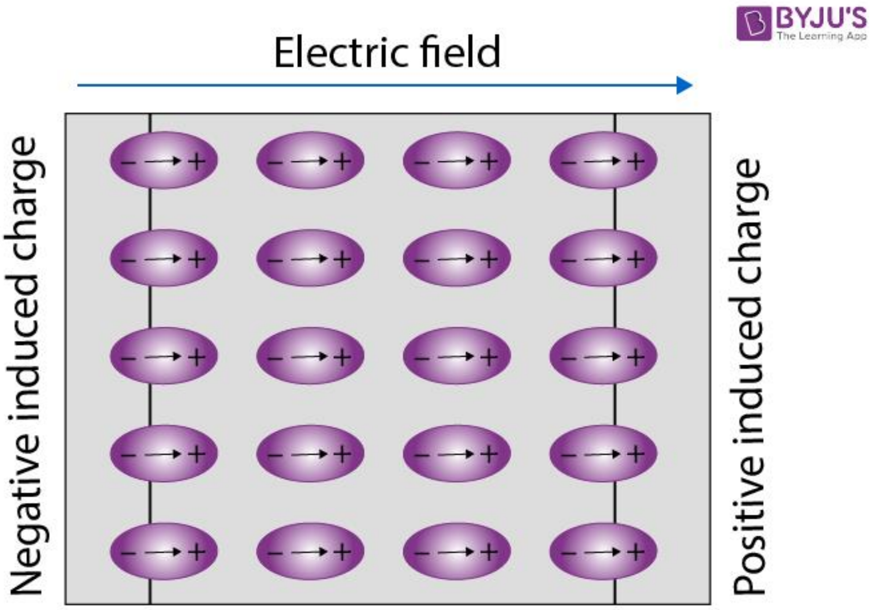
With respect to the atomic view, dielectric materials are classified into two categories.



Polar and non-polar molecules help us to understand the dielectric behaviour in an electric field.

Dielectric Polarisation

A dielectric may be made up of polar or non-polar molecules. But the net effect of an external field is almost the same, i.e., the external field will compel the molecules to align their dipole moments along its own direction.



Let us consider a dielectric slab in an electric field which is acting in the direction shown in the figure. The arrangement of charges within the molecules of the dielectric in the electric field is the same as shown in the figure. The positive charges move in the direction of the field, and the negative charges move in the opposite direction. In other words, the electric dipoles align themselves with the direction of the field. In this state, the entire dielectric and its molecules are said to be polarised.

The alignment of the dipole moments of the permanent or induced dipoles with the direction of the applied electric field is called polarisation.

Within the two extremely thin surface layers indicated by shaded regions, there is an excess negative charge in one layer and an excess equal positive charge in the other layer.

The induced charges on the surfaces of the dielectric are due to these layers. These charges are not free, but each is bound to a molecule lying on or near the surface. That is why these charges are called bound charges or fictitious charges. Within the remaining dielectric, the net charge per unit volume remains zero. Thus, although the dielectric is polarised, yet as a whole, it remains electrically neutral.

Obviously, the positive induced surface charge must be equal in magnitude to the negative induced surface charge. Thus, in polarisation, the internal state of the slab is characterised not by an excess charge but by the relative displacement of the charges within it.

Polarisation can thus also be thought of as a phenomenon in which an alignment of positive and negative charges takes place within the dielectric, resulting in no net increase in the charge of the dielectric.

What is Dielectric Loss?

Dielectric loss is the loss of energy that goes into heating a dielectric material in a varying electric field. Dielectric loss is measured utilizing the loss tangent (tan δ)

Effect on dielectric loss:

As per the above formula, we can ascertain that with an increase in frequency, the loss increases also with an increase in voltage the value of dielectric loss increases. It is found that with the increase in temperature, the dielectric loss increases.

The mobility of charge carriers increases with temperature which increases the polarization that leads to high dielectric loss.

Dielectric loss refers to the energy dissipated as heat in a dielectric material when it is subjected to an alternating electric field. This phenomenon is crucial because it affects the efficiency and performance of electrical systems. Understanding what dielectric loss is and how it occurs can help in designing better, more efficient electrical components.

CH-5 MAGNETIC MATERIAL

INTRODUCTION

All substances show some kind of magnetic behaviour. After all, they are made up of charged particles: electrons and protons. It is the way in which electron clouds arrange themselves in atoms and how groups of these atoms behave that determines the magnetic properties of the material. The atom (or group of atoms) in effect becomes a magnetic dipole or a mini bar magnet that can align according to the magnetic field applied. The net effect of all these dipoles determines the magnetic properties of the magnetic materials.

Types of Magnetic Materials

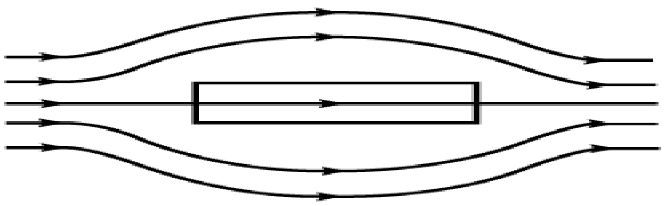
To study magnetic properties of magnetic materials, the material is usually placed in a uniform magnetic field and then the magnetic field is varied. There are three major kinds of magnetic behaviour:

- **Diamagnetic materials**
- **Paramagnetic materials**

- **Ferromagnetic materials**

1. **Diamagnetic materials**

A magnet generally repels diamagnetic materials. Technically, these solids produce an induced magnetic field in the opposite direction of an externally applied magnetic field and are repelled by it. The behaviour of paramagnetic materials is exactly the reverse of this phenomenon. Magnetic fields are created by the orbital motion of electrons on the atoms of diamagnetic materials, which forms small atomic current loops. When a material is subjected to an external magnetic field, these current loops tend to align in a way that opposes the applied field.



Diamagnetic Properties

After understanding the diamagnetic definition well, let us move further with the properties. Properties of the diamagnetic materials are:

1. The diamagnetic materials have all the paired electrons, and none of the electrons is the valence, resulting in the absence of atomic dipoles in these materials. This happens because the overall magnetic moment of each atom in the compound cancels out.
2. In the presence of the magnetic field, there is a repulsion between the diamagnetic substance and the magnet.
3. The field weakly repels the substances having diamagnetism; thus in the non-uniform field's presence, these substances move from the stronger region of the magnetic field to the weaker one.
4. In comparison to the magnetizing field, magnetization intensity is lower in the negative direction, and proportional.
5. Diamagnetic materials have lower and negative magnetic susceptibility.
6. The relative permeability is also a bit lower than unity.
7. The materials that exhibit diamagnetism do not obey Curie's Law. They are independent of the action of temperature.

2. Paramagnetic Material

Paramagnetic Materials are defined as the materials which get weakly magnetized in the direction of external magnetic field and lose their magnetic property when removed from external magnetic field

Magnetic Field lines through Paramagnetic material

Paramagnetic Material Examples

Examples of Paramagnetic Materials are,

- **Aluminum (Al)**
- **Platinum (Pt)**
- **Copper (Cu)**
- **Graphite**
- **Oxygen (O2)**
- **Manganese (Mn)**
- **Chromium (Cr)**

Properties of Paramagnetic Materials

The properties of Paramagnetic Materials are mentioned below:

1. Although the net atomic dipole moment of an atom is not zero, atoms of paramagnetic substances have a permanent dipole moment due to unpaired electron spin.
2. These objects are weakly attracted by magnets most of the times.
3. The paramagnetic rod aligns itself with the magnetic field because the magnetic field is stronger near the pole compared to that of along the body.
4. Magnetization is very small, positive and proportional to the magnetization field.
5. Magnetic susceptibility is very small.
6. The relative magnetic permeability is slightly less than 1. The magnetic field in the material is larger than the magnetization field.
7. The internal magnetic field lines of paramagnetic substances intensify.
8. The magnetization intensity of a paramagnetic substance is inversely proportional to temperature. Paramagnetic substances follow Curie's law, which says that magnetic susceptibility is inversely proportional to temperature.

Application of Paramagnetic Materials

Various properties of Paramagnetic materials are,

- **MRI (Magnetic Resonance Imaging):** Paramagnetic contrast agents are used to increase the visibility of certain tissues or structures in MRI. These contrast agents contain paramagnetic ions such as gadolinium, which help improve the contrast between different tissues in the body.

- **Electromagnetic Devices**: Paramagnetic materials are used in the construction of many electronic devices, including inductors and transformers.
- **Research and Analysis:** Paramagnetic materials are used for various research and analysis in the laboratory. For example, paramagnetic ions can be used as probes in spectroscopy and other analyzes to study the structure and properties of different substances.
- **Magnetic Bearings**: In some applications, magnetic bearings that take advantage of the magnetic properties of the materials can operate. These bearings can provide a non-contact, low-friction way to support rotating parts, reduce wear and improve the quality of rotating machinery.
- **Magnetic Separation:** Magnetic materials can be separated from non-magnetic materials using magnetic separation technology. This is particularly useful in industries such as mining.
- **Nuclear Magnetic Resonance (NMR) Spectroscopy**: Paramagnetic ions can affect NMR signals in NMR spectroscopy. Scientists use paramagnetic materials to study local regions and molecular interactions, providing valuable information in fields such as chemistry and biochemistry.

3. **Ferromagnetic Materials**

Ferromagnetic materials strongly magnetize in the direction of an applied magnetic field. A key concept here is a domain, which is a small area within these materials where electrons align due to an exchange interaction—essentially, unpaired electrons between atoms aligning with the magnetic field. This process, known as ferromagnetism, allows certain materials like cobalt, iron, and gadolinium to become permanent magnets.

Properties of Ferromagnetic Materials

- When a rod of this material is placed in a magnetic field, it rapidly aligns itself in the track of the field.
- It is strongly attracted by the magnet.
- The ferromagnetism mechanism is not present in liquids and gases.
- The intensity of magnetization (M), magnetic susceptibility (χ_m), relative permeability (μ_r), and magnetic flux density (B) of this material will be always prominent and positive.

What are the Applications of Ferromagnetism?

- The applications of a ferromagnetic substance are comprehensive. The hysteresis curve plays a vital role and it's of great importance.
- Ferromagnetism has its applications in transformers, electromagnets, and magnetic tape recording.

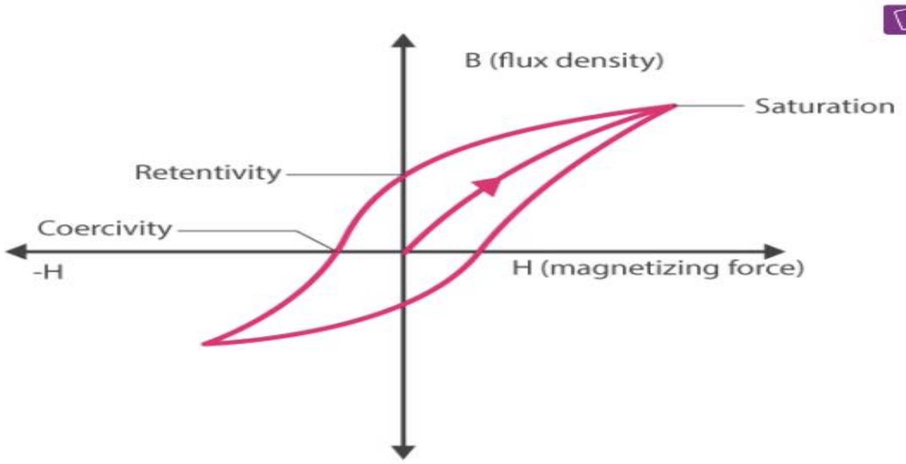
Difference Between Paramagnetic, Diamagnetic and Ferromagnetic Material			
Property	**Paramagnetic Materials**	**Ferromagnetic Materials**	**Diamagnetic Materials**
Behavior	Weakly attracted to external magnetic fields.	Strongly attracted to external magnetic fields, and can retain magnetization.	Weakly repelled by external magnetic fields.
Magnetic Moment	Alignment of magnetic moments with the applied field is temporary.	Spontaneous alignment of magnetic moments, leading to strong and persistent magnetization.	Alignment of magnetic moments opposite to the applied field is weak and temporary.
Origin of Magnetism	Due to unpaired electrons in the presence of an external magnetic field.	Arises from the alignment of atomic magnetic moments, which can persist even in the absence of an external field.	Induced by an external magnetic field; all electrons are paired.
Materials Examples	Iron, Aluminum, Platinum, Gadolinium.	Iron, Cobalt, Nickel.	Copper, Bismuth, Zinc.

Difference Between Paramagnetic, Diamagnetic and Ferromagnetic Material			
Property	**Paramagnetic Materials**	**Ferromagnetic Materials**	**Diamagnetic Materials**
Magnetic Susceptibility	Positive	High positive magnetic susceptibility.	Negative
Curie Temperature	Typically, there is no Curie temperature	Above the Curie temperature, ferromagnetic materials lose their magnetic properties.	Below the Curie temperature, diamagnetic materials exhibit weak repulsion.
Applications	MRI contrast agents, electromagnetic devices, research probes.	Permanent magnets, transformer cores, magnetic storage media.	Magnetic levitation, superconductors, screening of magnetic fields.
Interaction Range	Interaction is short-range and weak.	Interaction can extend over longer distances.	Interaction is weak and short-range.

Hysteresis

On removing the external magnetic field, a ferromagnetic material doesn't get demagnetised fully. To bring the material back to zero magnetisation, a magnetic field in the opposite direction has to be applied. The property of ferromagnetic materials retaining magnetisation after the external field is removed. This is called hysteresis.

The magnetisation of the material measured in terms of magnetic flux density (B) when plotted against the external applied magnetic field intensity (H) will trace out a loop. This is called the hysteresis loop.



Retentivity is the magnetic flux density that remains when the magnetising force is reduced to zero.

Coercivity is the strength of the reverse magnetising field that must be applied to completely demagnetise the material.

Curie Temperature

Ferromagnetic property depends on temperature. At a high enough temperature, ferromagnetic substances become paramagnetic. The temperature at which this transition occurs is called Curie's temperature. It is denoted by T_C.

Curie point : It is the temperature at which certain magnetic materials undergo a sharp change in their magnetic properties.

Magnetostriction: It is a property of ferromagnetic materials which causes them to expand or contract in response to a magnetic field.

What is a Hard Magnetic Material?

Hard magnetic materials are those types of magnetic materials that maintain a constant magnetic property after magnetization at once. Therefore, the hard magnetic materials are sometimes also termed as **permanent magnetic materials**.

Hard magnetic materials have high coercivity and low permeability. For this reason, it is quite difficult to demagnetize the hard magnetic materials. The area of hysteresis loop for hard magnetic materials is large, consequently these materials have large hysteresis loss. Although, the hard magnetic materials can store relatively high energy in the magnetic field. In practice, the hard magnetic materials are widely used for making permanent magnets. Some common examples of permanent magnetic materials are AlNiCo alloy, FeCrCO alloy, permanent magnet ferrites, etc

What is a Soft Magnetic Material?

A type of magnetic material which can be easily magnetized and demagnetized is known as soft magnetic material. The soft **magnetic materials** have low value of coercivity and high value of permeability.

The area of hysteresis loop of the soft magnetic materials is small, as a result the hysteresis loss in case of soft magnetic materials is less. Generally, the soft magnetic materials have high resistivity. Consequently, the eddy current loss occurring in these materials is also low.

Soft magnetic materials store less energy in the magnetic field as compared to the hard magnetic materials. Since, the soft magnetic materials have high permeability, hence these are most suitable for making magnetic circuits for carrying flux in electrical machines. The most extensively used soft magnetic materials in electrical machines are silicon sheet steel and several soft ferrites. These materials are also used for making the electromagnets.

Difference between Hard Magnetic Material and Soft Magnetic Material

Basis of Difference	**Hard Magnetic Materials**	**Soft Magnetic Materials**
Definition	The magnetic materials that can retain their magnetism even after removal of external magnetic field, and are difficult to magnetized and demagnetized are known as hard magnetic materials.	The magnetic materials that can be easily magnetized and demagnetized are known as soft magnetic materials.
Magnetism	The magnetism of hard magnetic materials is constant.	The magnetism of soft magnetic materials is temporary.

Area of hysteresis loop	For the hard magnetic materials, the area of the hysteresis loop is large.	For the soft magnetic materials, the area of the hysteresis loop is small.
Ease of magnetization	Hard magnetic materials cannot be magnetized easily.	Soft magnetic materials can be easily magnetized.
Coercivity	The coercivity of hard magnetic materials is high.	Soft magnetic materials have relatively low coercivity.
Retentivity	Hard magnetic materials have large value of retentivity.	Soft magnetic materials have small value of retentivity.
Movement of domain walls	The domain walls of the hard magnetic materials do not move easily.	The domain walls of soft magnetic materials can move easily.
Value of H for magnetization	Hard magnetic materials require very large value of magnetizing force (H) for magnetization. It is because, they need comparatively more energy for the movement of domain walls.	Soft magnetic materials require comparatively low value of magnetizing force (H) for magnetization.
Hysteresis loss	Due to large area of hysteresis loop, the hysteresis loss in case of hard magnetic materials is high.	Soft magnetic materials have low hysteresis loss.
Permeability	The permeability of hard magnetic materials is low.	The permeability of soft magnetic materials is high.
Susceptibility	Hard magnetic materials are less susceptible as a result these are less influenced by the external magnetic field.	The susceptibility of soft magnetic materials is high. Consequently, the

		external magnetic field can easily influence them.
Eddy current loss	Hard magnetic materials have low electrical resistance. As a result, the eddy current loss in these materials is high.	Due to low value of electrical resistance of soft magnetic materials. These materials have less eddy current loss.
Energy stored	Hard magnetic materials can store high energy in the magnetic field.	Soft magnetic materials store less energy in the magnetic field.
Applications	Hard magnetic materials are used in a wide range of applications like in, making permanent magnets, microphones, loudspeakers, motor drives, injection pumps, printers, clocks, measuring instruments, lifting apparatus, robotics, MRI machine and many other medical instruments, etc.	Soft magnetic materials are extensively used in electrical engineering such as for making core the electromagnetics, core of electrical machines like transformer, motor, generator, parts of measuring devices, etc.
Examples	The examples of hard magnetic materials are alnico, ferrites, rare earth cobalt, cobalt platinum, etc.	Some popular examples of soft magnetic materials are pure iron with small carbon content, siliconiron alloy, nickel-iron alloy, etc.

CH-6 SPECIAL PURPOSE MATERIAL

A structural material is a material that is used to construct or support a load-bearing structure, such as buildings, bridges, or vehicles.

PROTECTIVE MATERIAL

LEAD

- Lead is an element of the periodic table with an atomic number of 82.
- Lead (Pb) is a metal which has been used by humans for centuries dating back to 7000 BC.
- The element is present in various minerals in minute quantities excluding sulphide and lead glance(PBS) which is used to produce the metal around the world.

Properties of Lead

- Lead (Pb) is a white lustrous metal with a soft texture and is highly malleable.
- The metal is highly corrosion-resistant, in addition to not being a poor conductor of electricity.
- The metal in its powdered form produces a bluish-white flame when burnt in the air.
- Once mixed with fluorine at room temperature forms lead fluoride.

Uses of Lead

- It is a metal that has been used since Roman times for making paints and pipes corrosion resistant.
- Used in car batteries and a major ingredient of lead-acid batteries.
- For soldering parts of electrical equipment.
- As electrodes in electrolysis processes.

BIMETALS

A **bimetal** is defined as an object that is composed of two separate metals joined together by a metallurgical process. Unlike alloys, which are mixtures of two or more metals, bimetals consist of layers of different metals that retain their individual attributes. Bimetals can also be called bimetallic products or bicomponent materials.

Bimetals have two distinct metallic zones that work together mechanically and electrically as a single unit. The main benefit of bimetals is combining the best qualities of each metal into one product. For instance, bimetals can merge the strength of one metal with the corrosion resistance of another or the conductivity of one metal with the cost-effectiveness of another.

Bimetals are used in many industries and applications, including electrical conductors, contacts, thermostats, thermometers, protective devices, clocks, coins, cans, and blades. This article explores the working principle, common combinations, and major applications of bimetals.

FUSE

Working Principle of an Electrical Fuse

To understand the working principle behind an electrical fuse, two critical concepts should be kept in mind

1. Current flows in a loop
2. Heating effect of current

- Electric current can flow through a conductor only when the circuit formed is complete. If there is a break in the loop, electric charges cannot flow through.
- This is also how switches operate.
    - For example, when you put on the light switches at home, the lights come on because you have just completed the circuit allowing charges from the power source to flow through and power your lights.
- When current passes through a conductor, the different electrical components of the circuit like the devices attached or even the wire itself, offer resistance to the current flow.
    - The work done to overcome this resistance presents itself in the form of heat.
    - This is a simple explanation of the "heating effect" of current.

Principle of Electrical Fuse

- The primary use of an electric fuse is to protect electrical equipment from excessive current and to prevent short circuits or mismatched loads.
    - Electrical fuses play the role of miniature circuit breakers.
    - Apart from protecting equipment, they are also used as safety measures to prevent any safety hazards to humans.
- The fuse wire in an electrical fuse is selected in such a way that it does not face any damage when the normally stipulated amount of current flows through the circuit.

  - Under normal conditions, the fuse wire is a part of the circuitry, contributing to a complete loop for charges to flow through it.
  - However, when an excessive amount of current flows through the fuse wire, the heating effect of the current causes the fuse wire to melt.
  - This is because the fuse wire is chosen such that it has a low melting point.
  - This causes the loop to break thereby stopping the flow of charges in the circuit.
- It is important to select a fuse that is properly specified for the circuit in consideration.
  - For example, if the fuse that is used is underrated, then it will fail even under normal current conditions, unnecessarily breaking the circuit loop.
  - If it is overrated, then it will not break the circuit when required and cause equipment damage and failure and may even present itself as a safety hazard.

ll not break the circuit when required and cause equipment damage and failure and may even present itself as a safety hazard.

Function of Fuse

In the field of electrical engineering, a fuse is a device that provides overcurrent protection to the functional electrical circuit. Here, we have listed a few major functions of the fuse.

- Acts as a barrier between the electric circuit and the human body
- Prevents device failure due to faulty circuit operation
- Fuse prevents short-circuits
- Prevents overload and blackouts
- Prevents damage that is caused due to mismatched loads

The markings on the fuse carry information such as the Ampere rating, voltage rating, and interruption rating.