# NILASAILA INSTITUTE OF SCIENCE
# &
# TECHNOLOGY

SERGARH-756060, BALASORE (ODISHA)
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# ELECTRICAL ENGINEERING MATERIAL

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3RD SEMESTER

# CONTENTS

# CHAPTER-1

# (CONDUCTING MATERIAL)

**Conducting material:**

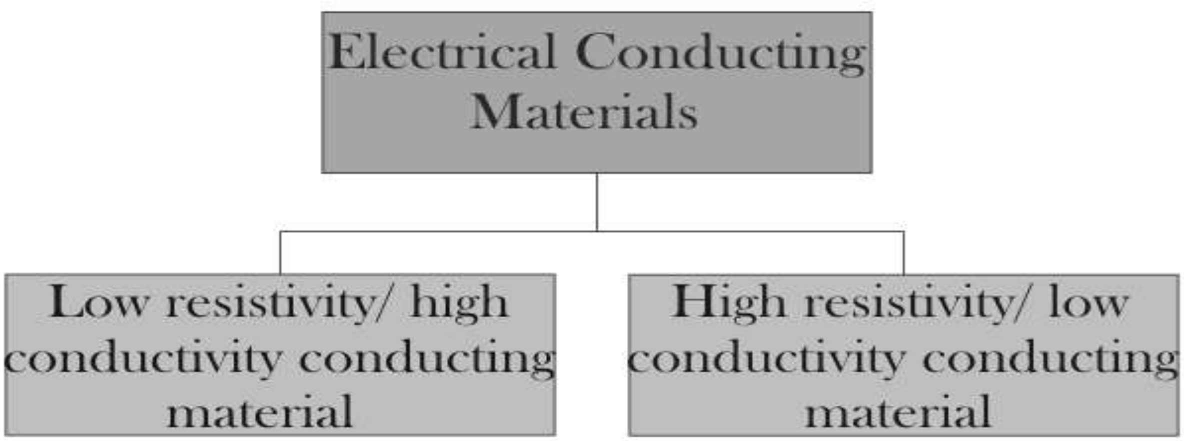
- The materials which conduct electricity due to free electrons when an electric potential difference is applied across them are known as conducting materials. .
- Conducting materials are good conductors of electricity and heat.
- Gold, silver, copper, aluminum are the examples of conducting materials

**Resistivity:**

- Resistivity is a measure of the resistance of a given size of a specific material to electrical conduction.
- Materials that conduct electrical current easily are called conductors and have a low resistivity.
- Those that do not conduct electricity easily are called insulators and these materials have a high resistivity.

**Factors effecting the resistivity of electrical materials are –**

1. Temperature.
2. Alloying.
3. Mechanical stressing.
4. Age Hardening.
5. Cold Working.



**Application of low resistivity material**

- A material with low resistivity means it has low resistance and thus the electrons flow smoothly through the material
- For example, Copper and Aluminum ave low resistivity. Good conductors have less resistivity.

**i. Copper:**

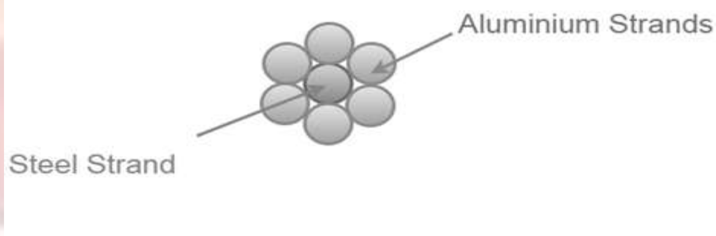
- It is most widely used metal because soft its high conductivity .
- Silver has the lowest resistivity but due to its high cost it is not used as conducting material.
- Copper is available in two forms, that is annealed copper and hard drawn copper, for use as conducting material.
- Hard drawn copper is about 4% less conducting than annealed copper, but has more tensile strength and is used in transmission and distribution lines where conductors have to be stretched.

**ii. Aluminum:**

- Aluminium is available in various forms such as oxides, sulphates, silicates, phosphates, etc.
- Pure aluminium is softer than copper, so can be rolled into thin sheets
- Use of aluminium as an electrical material, particularly in the aircraft industry, has considerable advantages because of the saving in weight involved.
- electrochemical plants are enormous users of aluminium busbars, because electrolytic cell operators with heavy currents at low voltages and to carry these current, massive bars are required.
- Aluminium, because of its lightness, is being used more and more for such busbars.
- The current carrying capacity of aluminium being 75% that of copper, and its density being approximately one-third that of copper,
- aluminum busbar is only about half the weight of copper busbar of equal current carrying capacity.

**Stranded Conductors**

- Stranded conductors are very much use for transmission and distribution line.
- A stranded conductor is consists of several thin wires of small cross sectional area called stranded conductors.




**Stranded Conductor**

- At the center 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 aluminum 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 it over long distance.

**ACSR**

- Aluminium conductor steel-reinforced cable (ACSR) is a type of high-capacity, high-strength stranded conductor typically used in overhead power lines.
- The outer strands are high-purity aluminium, chosen for its good conductivity, low weight and low cost.

**Bundle conductor**

A bundle conductor is a conductor made up of two or more sub-conductors and is used as one phase conductor.

- For voltages greater than 220 kV it is preferable to use more than one conductor per phase which is known as Bundle conductor.

**Advantages of Bundled Conductors**

- Bundling of conductors leads to reduction in line inductance.
- Bundle conductors ability to reduce corona discharge.
- When power is being transferred at very high voltages using a single conductor, the voltage gradient around it is high, and there is a high chance that the corona effect will occur, especially in bad weather conditions.
- Reduction in communication line interference due to reduction in corona.

High resistivity material and their application

**(1)Tungsten**

- This material is used in electronic and vacuum engineering.
- It is also used in electron, X-ray and other kinds of tubes.
- The tungsten filament is made in straight, coiled or coiled-coil form.

**(2) Carbon**

- Carbon is used in automatic voltage regulators for making the pressure sensitive pile resistors.
- It is used in the manufacture of welding electrodes, fixed and variable resistors for light current and contacts of certain classes of D.C. switch gear.

Super conducting materials applications

- Power transmission cables.
- Transformers.
- Motors and generators.

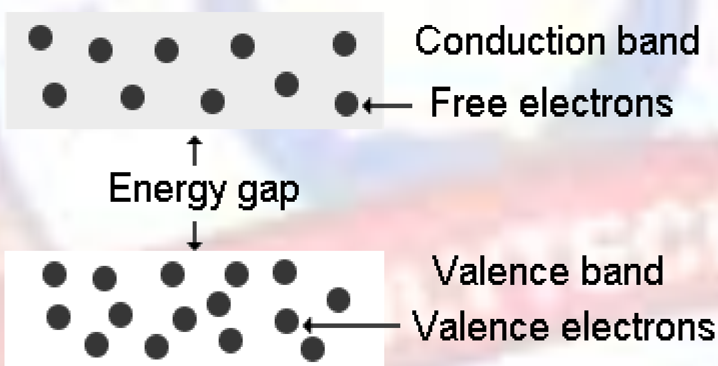
# CHAPTER 2

# SEMICONDUCTING MATERIAL

- Semiconductors are materials which have a conductivity between conductors (generally metals) and nonconductors or insulators (such as most ceramics).
- Semiconductors can be pure elements.

## ENERGY BAND THEORY

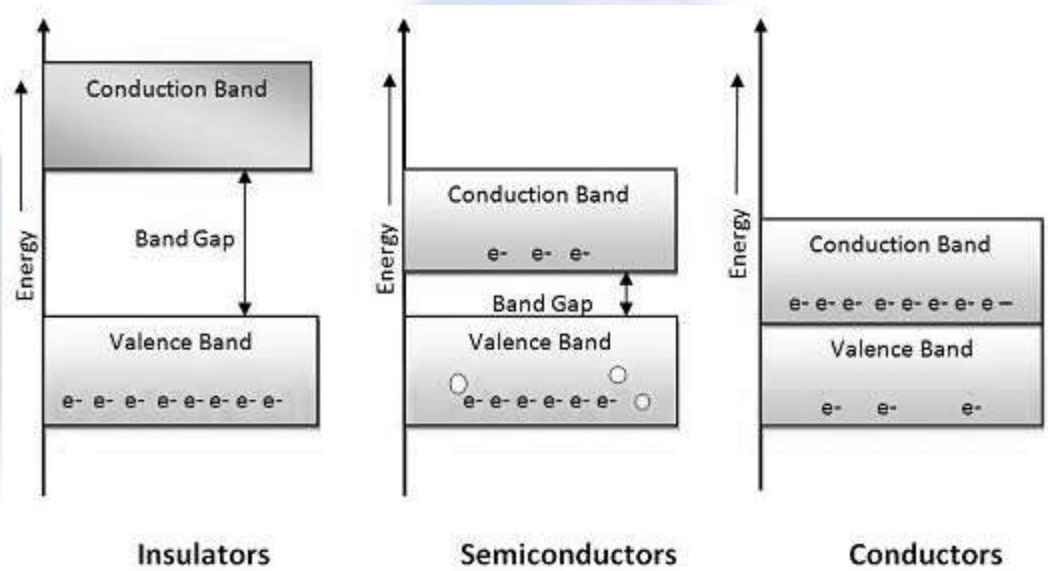
- Energy has to be supplied to move electrons away from the nucleus of the atom.
- The valence electrons have the highest energy levels of the electrons that are still bound to their parent atoms.
- Additional energy is required to completely remove an electron from the atom, so free electrons have higher energy levels than valence electrons.
- This can be illustrated with an energy band diagram, which shows two energy levels, a valence band and a conduction band.
- Valence electrons are located in the valence band and the free electrons in the higher conduction band.




- In semiconductors there is a gap between the valence and conduction bands. So energy must be supplied for valence electrons to "jump up" to the conduction band.
- This reflects the fact that energy must be supplied to remove valence electrons from their parent atoms and become free electrons.
- In insulators this gap is much larger, to represent the significantly higher energy levels that would be needed, to "pull" electrons from their parent atoms.
- In metals the valence band and conduction band actually overlap.
- So in metals, valence electrons can move easily into the conduction band, producing a large number density of free electrons.

**Insulator**

Any material that keeps energy such as electricity, heat, or cold from easily transferring through is an insulator. Wood, plastic, rubber, and glass are good insulators.




**Semiconductor**

- Semiconductors are materials which have a conductivity between conductors (generally metals) and nonconductors or insulators (such as most ceramics).
- Semiconductors can be pure elements.

**Conductor**

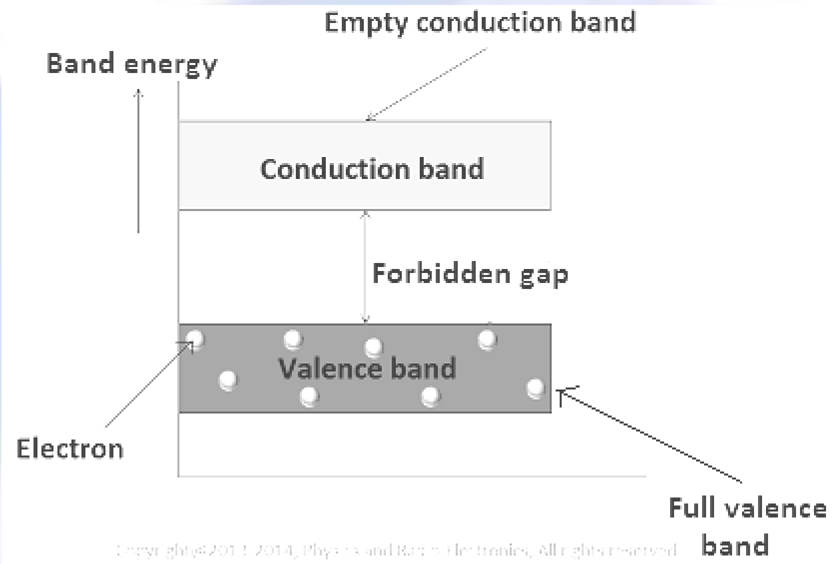
- A conductor is a material which electricity, heat or sound can flow through. An electrical conductor conducts electricity.
- The ability to conduct electricity is called electrical conductivity. Most metals, like iron and copper, are electrical conductors.
- These metals are used to make wires to carry electric current.

**Covalent bond**

- A covalent bond, also called a molecular bond, is a chemical bond that involves the sharing of electron pairs between atoms.
- These electron pairs are known as shared pairs or bonding pairs, and the stable balance of attractive and repulsive forces between atoms, when they share electrons, is known as covalent bonding.

**Forbidden energy gap**

- Forbidden energy gap is the gap between valence band and conduction band. In other words the energy required by an electron to jump from valence band to conduction band.
- Forbidden energy gap, also known as band gap refers to the energy difference between the top of valence band and the bottom of the conduction band in materials.
- Current flowing through the materials is due to the electron transfer from the valence band to the conduction band

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| PARAMETER | INTRINSIC SEMICONDUCTOR | EXTRINSIC SEMICONDUCTOR |
|---|---|---|
| Form of semiconductor | Pure form of semiconductor. | Impure form of semiconductor. |
| Conductivity | It exhibits poor conductivity. | It possesses comparatively better conductivity than intrinsic semiconductor. |
| Band gap | The band gap between conduction and valence band is small. | The energy gap is higher than intrinsic semiconductor. |
| Fermi level | It is present in the middle of forbidden energy gap. | The presence of fermi level varies according to the type of extrinsic semiconductor. |
| Dependency | The conduction relies on temperature. | The conduction depends on the concentration of doped impurity and temperature. |
| Carrier concentration | Equal amount of electron and holes are present in conduction and valence band. | The majority presence of electrons and holes depends on the type of extrinsic semiconductor. |
| Type | It is not classified. | It is classified as p type and n |

| | | |
|---|---|---|
| | | type semiconductor. |

**N-TYPE MATERIAL**

- An N-type semiconductor is a type of material used in electronics. It is made by adding an impurity to a pure semiconductor such as silicon or germanium.
- The impurities used may be phosphorus, arsenic, antimony, bismuth or some other chemical element. They are called donor impurities.

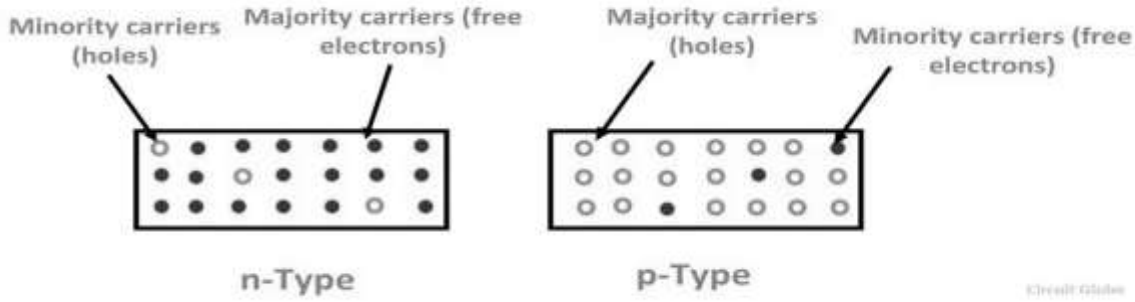
**P-TYPE MATERIAL**

- A p-type semiconductor is a type of semiconductor. When the trivalent impurity is added to an intrinsic or pure semiconductor then it is said to be an p-type semiconductor.
- Trivalent impurities such as Boron (B), Gallium (Ga), Indium(In), Aluminium(Al) etc are called acceptor impurity.

| BASIS OF DIFFERENCE | P TYPE SEMICONDUCTOR | N TYPE SEMICONDUCTOR |
|---|---|---|
| Group of Doping Element | In P type semiconductor III group element is added as doping element. | In n type semiconductor V group element is added as doping element |
| Majority Carriers | Holes are majority carriers | Electrons are majority carriers |
| Minority Carriers | Electrons are minority carriers | Holes are minority carriers |
| Fermi level | It lies betwwn energy band and valency band | It lies between energy band and conductor band |
| Movement of Majority carriers | Majority carriers move from higher to lower potential | Majority carriers move from lower to higher potential. |
| Type of impurity added | Trivalent impurity l added | Pentavalent impurity added. |

**Majority and Minority Carriers**

- In an n-type semiconductor, the electrons are the majority carriers whereas, the holes are the minority carriers.
- In the p-type semiconductor material, the holes are the majority carriers, whereas, the electrons are the minority carriers as shown in the figures below.




- When a small amount of Pentavalent impurity is added to a pure semiconductor.
- it provides a large number of free electrons in the crystal forming the n-type semiconductor.
- Some of the covalent bonds break even at the room temperature, releasing a small number of electron-hole pairs.
- Thus, an n-type semiconductor contains a large number of free electrons and a few numbers of holes. This means the electron provided by Pentavalent impurity added and a share of electron-hole pairs.
- Therefore, in n-type semiconductor, the most of the current conduction is due to the free electrons available in the semiconductor.
- Similarly, in the p-type semiconductor, the holes are in the majority as compared to electrons, and the conduction takes place because of the very few electrons which are present in the minority.

**Applications OF Rectifier**

1. Because of its property of rectification, it can be utilized as a part of the power supply circuitry.
2. It can be utilized in power supply units with switching-mode technique.
3. During the detection of the amplitude for the modulated radio signals rectifiers are used.
4. In order to supply the voltage in a polarized manner for the purpose of wielding rectifiers are used.

**Applications Photovoltaic**

- (PV) cell is the technical term for solar cell, which is used to convert sunlight directly into electricity. ...
- Nowadays PV technology is being used to power homes and commercial buildings, and even in large power stations of several utility companies.

**Application of solar cells.**

- Solar cells are very useful in powering space vehicles such as satellites and telescopes.
- They provide a very economical and reliable way of powering objects which would otherwise need expensive and cumbersome fuel sources.

**Application of transistor**

- Transistors are also used to switch electronic signals. .
- Most types of transistors are packaged individually but can also be included in an integrated circuit.

**Photoconductive cell**

- When a photoconductive material is connected as part of a circuit, it functions as a resistor whose resistance depends on the light intensity. ..
- . The most common application of photoresistors is as photodetectors, i.e. devices that measure light intensity.

# CHAPTER-3

# (INSULATING MATERIAL)

**Definition:**

- The material which does not allow the electricity to pass through them is known as an electrical insulating material.
- The charge of the insulating material does not move freely, or in other words, it provides the high resistive path to the electric current through which it is nearly impossible for the electric current to conduct through it.
- It is used in the overhead transmission line .

**The insulating material should have the following properties.**

1. The material must have high mechanical strength so that it carries the tension and weight of the conductors.
2. They must have high dielectric strength.
3. The material is highly resistive for preventing the flow of leakage current from the conductor to earth.
4. The material is non-porous and free from impurities.
5. The electrical and chemical property of the material should not be affected by the temperature.

**Mechanical Properties of Insulating Materials**
**1. Tension and Compression:**

- The conductors of transmission and distribution systems of overhead lines are supported by means of insulators to avoid leakage of current through the supports to the earth.
- When a tensile load exists on it, it should be able to withstand and should not give way mechanically.

**2. Resistance to Abrasion:**

1. insulator used between the commutator segments which are subjected to abrasive action during the running of the motor.
2. The insulation qualities should be such that it should withstand this

**Viscosity :**

- In liquid insulators, viscosity plays an important role.

- It affects the manufacturing process.
- Low viscosity liquids are more mobile .
- Liquid insulations should not contain impurities as it will also affect the viscosity and the performance

**Electrical Insulating Material**

- The material which does not allow the electricity to pass through them is known as an electrical insulating material.
- The charge of the insulating material does not move freely,and it provides the high resistive path to the electric current through which it is nearly impossible for the electric current to conduct through it.
- It is used in the overhead transmission line between the tower and conductor for preventing the flow of electric current from the conductor to earth.

**Properties of an Electrical Insulating Material**

- The material must have high mechanical strength so that it carries the tension and weight of the conductors.
- They must have high dielectric strength.
- The material is highly resistive for preventing the flow of leakage current from the conductor to earth.
- The material is non-porous and free from impurities.
- The electrical and chemical property of the material should not be affected by the temperature.

**Insulating material characteristics**

- Large insulating resistance.
- High dialectic strength.
- Uniform viscosity
- it keeps the electric losses as low as possible and electric stresses uniform under high voltage difference.
- Least thermal expansion.
- When exposed to arcing should be non-ignitable.
- Should be resistance to oils or liquids, gas fumes, acids .
- Should have no deteriorating effect on the material, in contact with it

**Classification According to Substances and Materials:**

**(i) Solids (Inorganic and Organic):**

Mica, wood, slate, glass, porcelain, rubber, cotton, silk, rayon, paper and cellulose materials etc.

**(ii) Liquids (Oils and Varnishes):**

Linseed oil, refined hydrocarbon mineral oils, spirit and synthetic varnishes etc.

**(iii) Gases:**

Dry air, carbon dioxide, nitrogen etc.

Insulating materials, on the basis of their physical and chemical structure may be classified in various categories as follows:

**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 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:**

- Insulating liquid 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.

**Insulating Gas**

A dielectric gas, or insulating gas, is a dielectric material in gaseous state. .. Dielectric gases are used as electrical insulators in high voltage application

**Properties of insulating Gases**

- Utmost dielectric strength.
- Fine heat transfer.
- Incombustible.
- Chemical idleness against the construction material used.
- Inertness.
- Environmentally non poisonous.
- Small temperature of condensation.

- High thermal constancy.
- Acquirable at low cost

**Application of Insulating Gases**

- It is used in Transformer,
- Radar waveguides
- Circuit Breakers,
- Switchgears,
- High Voltage Switching, Coolants.
- They are usually used in high voltage application

**Glass**

- It has a higher tensile strength compared to porcelain insulator.
- As it is transparent in nature the is not heated up in sunlight as porcelain.
- The impurities and air bubbles can be easily detected inside the glass insulator body because of its transparency.

# CHAPTER – 4
# (DIELECTRIC MATERIAL)

A dielectric material is a substance that is a poor conductor of electricity, but an efficient supporter of electrostatic field.

**Dielectric constant of permittivity**

- The dielectric constant (k) of a material is the ratio of its permittivity ε to the permittivity of vacuum ε o , so k = ε / ε o.
- The dielectric constant is therefore also known as the relative permittivity of the material.
- the dielectric constant is just a ratio of two similar quantities, it is dimensionless.

**Dielectric loss**

- Dielectric loss, loss of energy that goes into heating a dielectric material in a varying electric field
- . For example, a capacitor incorporated in an alternating-current circuit is alternately charged and discharged each half cycle.

**Dielectric polarization**

- Dielectric polarization is describe the behavior of a material when an external electric field is applied on it.
- A simple picture can be made using a capacitor as an example. The figure below shows an example of a dielectric material in between two conducting parallel plates

**Dielectric breakdown**

- dielectric breakdown occurs when current flows through an electrical insulator.
- The voltage at which the insulator becomes electrically conductive is called its breakdown voltage.

**Applications of dielectrics are**

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

# CHAPTER-5

# (MAGNETIC MATERIAL)

Magnetic materials are those materials that can be either attracted or repelled when placed in an external magnetic field and can be magnetized themselves. example-iron

On the basis of orientation, the magnetic materials are classified into four categories

(a) Diamagnetic

(b) Paramagnetic

(c) Ferromagnetic

(d) Anti – ferromagnetic

1. **.Diamagnetic materials**

- These materials are magnetized when placed in a magnetic field.
- Magnetic dipoles in these substances tend to align in opposition to the applied field.
- They produce an internal magnetic field that opposes the applied field and the substance tends to repel the external field around it.

Ex: Gold, water, mercury and even animals

2. **Paramagnetic materials**

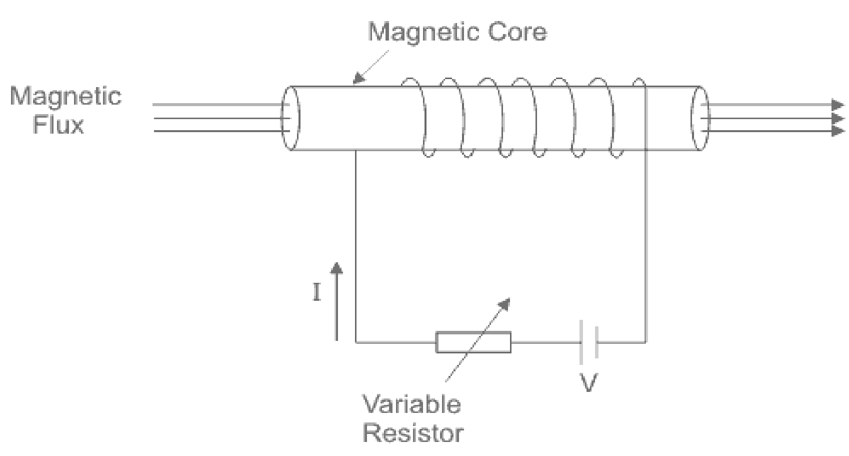
- In these materials the magnetic dipoles in the Magnetic Materials tend to align along the applied magnetic field and thus reinforcing the applied magnetic field.
- Such substances are attracted by a magnet if it applies a sufficiently strong field.
- It must be noted that such materials are still feeble magnetized and the magnetization disappears as soon as the external field is removed.
- Ex: Liquid oxygen, sodium, platinum, salts of iron and nickel.
  3 .ferromagnetic materials
- Most of the ferromagnetic materials are metals.
- Common examples of ferromagnetic substances are Iron, Cobalt, Nickel, etc.
- In addition, metallic alloys and rare earth magnets are also classified as ferromagnetic materials.
- Magnetite is a ferromagnetic material which is formed by the oxidation of iron into an oxide.

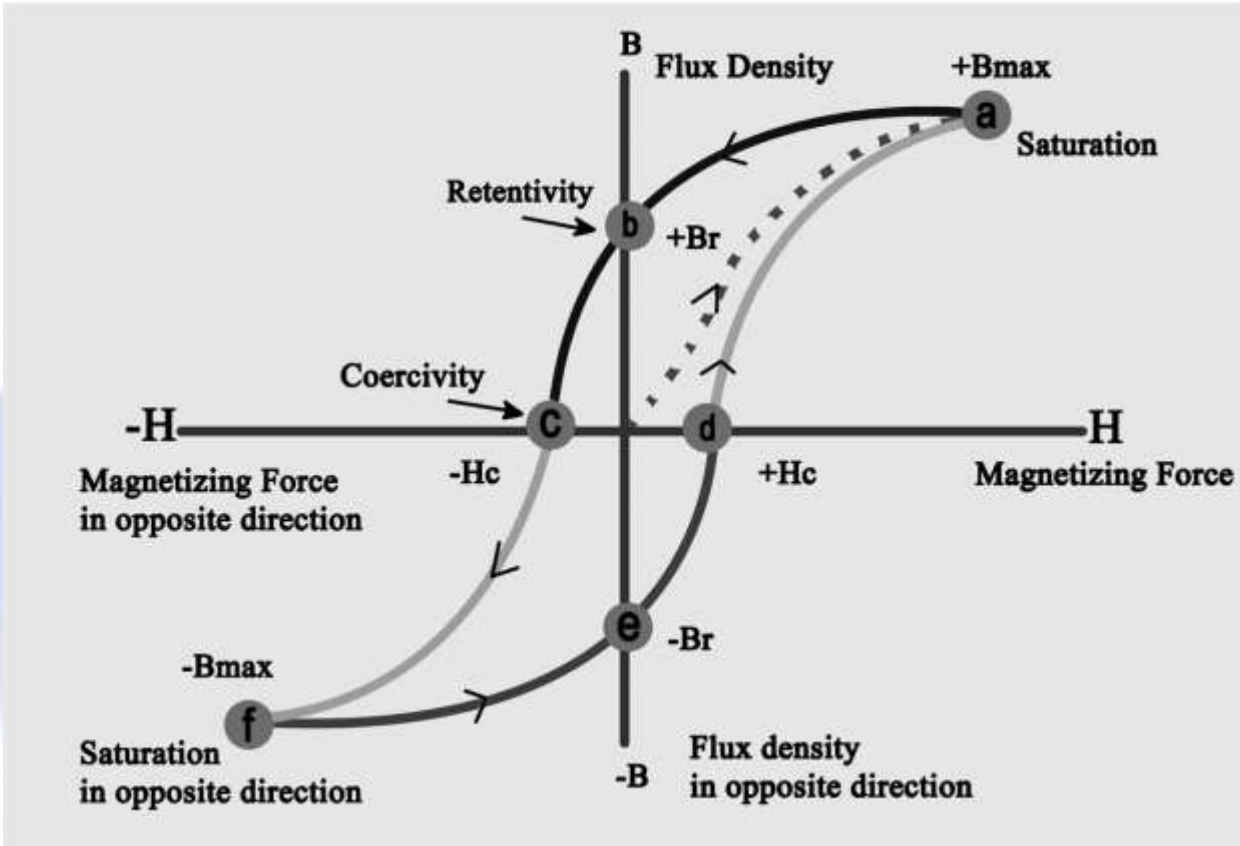
**Magnetization curve and Hysteris**

- Hysteris in ferromagnetic materials - BH curve.
- Hysteresis is present in ferromagnetic material
- . When a magnetic field is applied, the ferromagnetic material will become magnetic.
- Hysteresis loop is a four quadrant B-H graph from where the hysteresis loss, coercive force and retentively of s magnetic material are obtained.
- If a magnetic material to use as a core around which insulated wire is wound.
- The coils is connected to the supply (DC) through variable resistor to vary the current I.
- Current I is directly proportional to the value of magnetizing force (H) as

$$H = \frac{NI}{l}$$

  Where, N = no. of turn of coil and l is the effective length of the coil.
- magnetic flux density of this core is B which is directly proportional to magnetizing force H.





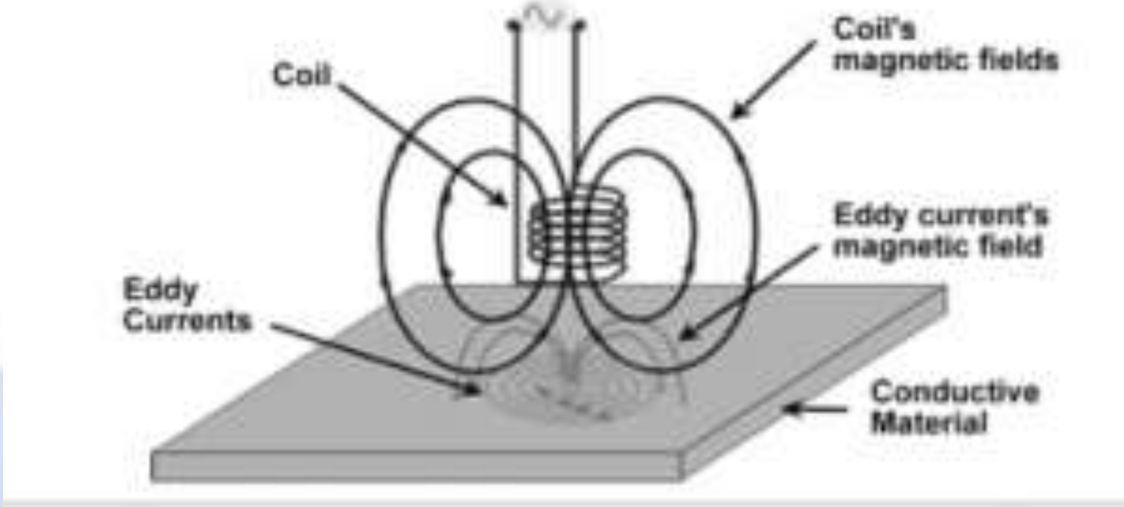

- Hysteresis of a magnetic material is a property by virtue of which the flux density (B) of this material lags behind the magnetizing force (H)
- Coercive force is defined as the negative value of magnetizing force (-H) that reduces residual flux density of a material to zero'
- Residual flux density is the certain value of magnetic flux per unit area that remains in the magnetic material without presence of magnetizing force (i.e. H = 0).
- Retentivity defined as the degree to which a magnetic material gains its magnetism after magnetizing force (H) is reduced to zero.

**The advantages of hysteresis loop are given below**.

- Smaller hysteresis loop area symbolizes less hysteresis loss.
- Hysteresis loop provides the value of retentivity and coercivity of a material. Thus the way to choose perfect material to make permanent magnet, core of machines becomes easier.
- From B-H graph, residual magnetism can be determined and thus choosing of material for electromagnets is easy.

**Eddy Current**

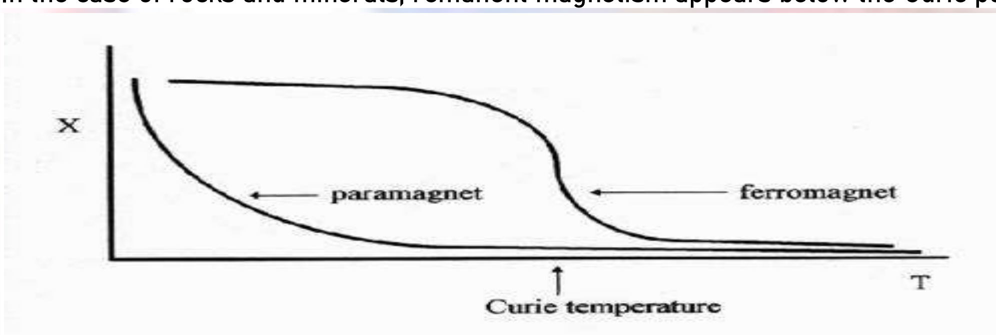
- Eddy currents are loops of electrical current induced within conductors by a changing magnetic field in the conductor according to Faraday's law of induction.
- Eddy currents flow in closed loops within conductors, in planes perpendicular to the magnetic field.




- In Lenz's law, experiments done to explain the eddy currents.
- The first test showed that inside a solenoid a soft iron core is introduced and it is connected to the alternating electromotive force.
- When the metallic disc is placed over the soft iron core, the circuit is switched on and when the circuit is turned on the metallic disc is thrown up away from the iron core.

**Curie point**

- In Curie point, temperature at which certain magnetic materials undergo a sharp change in their magnetic properties.
- In the case of rocks and minerals, remanent magnetism appears below the Curie point.




**Properties of Hard Magnetic Materials**

- Utmost retentively and coercively.
- Value of energy product (BH) will be large.
- The shape of BH loop is nearly rectangle.
- High hysteresis loop.
- Small initial permeability.

**Application of Hard magnetic materials**

- Automotive: motor drives for fans, wipers, injection pumps; starter motors; Control for seats, windows etc.
- Telecommunication: Microphones, Loud Speakers, Telephone Ringers etc.
- Data processing: Printers, Stepping Motors, Disc Drives and Actuators.
- Consumer electronics: Home computers, Clocks, DC Motors for showers etc.
- Electronic and instrumentation: Energy Meter Disc, Sensors, Dampers etc.
- Industrial: Lifting apparatus, Robotics, Meters etc.
- Astro and aerospace: Auto-compass, Couplings, Instrumentation etc.
- Biosurgical: NMR/MRI body scanner

**Properties of Soft Magnetic Materials**

- Utmost permeability.
- Slight coercive force.
- Small hysteresis loss.

# CHAPTER-6
# (MATERIAL FOR SPECIAL PURPOSE)

**Structural materials**

1. Structural materials are materials used or studied primarily for their mechanical properties, as opposed to their electronic, magnetic, chemical or optical characteristics.
2. This can include a materials response to an applied force, whether this response is elastic or plastic, its hardness, and its strength.
3. Bimetals
4. The working of bimetals is based on the theory that a metal expends on heating and contracts on cooling. If we consider a strip of metal of length of l.
5. When the temperature increases, it length increased. The increase in length of strip due to rise in temperature is related by Coefficient of linear thermal expansion.
6. It denoted by "$\alpha_L$"
7. Bimetal is consists of two strips of two different metals having different Coefficient of linear thermal expansion, welded together lengthwise.

**Protective Material**

- Protecting Material used for manufacturing combat clothing should be capable of protecting the wearer.

**Fuse and Fuse Material**

1. Fuse is an essential device used in electrical circuits which gives the protection from the over current.
2. It comprises a strip or a metal wire that dissolves when the heavy flow of current supplies through it
3. The fuse element is made of zinc, copper, silver, aluminum, or alloys to provide stable and predictable characteristics.
4. The fuse ideally would carry its rated current indefinitely, and melt quickly on a small excess.
5. The material used for fuse elements must be of low melting point, low ohmic loss, high conductivity, low cost and free from detraction.
6. The material used for making fuse element has a low melting point such as tin, lead, or zinc.
7. A low melting point is, however, available with a high specific resistance metal .

**Soldering Material**

1. Solder alloys are usually formed of tin (Sn) and lead (Pb) with elements, such as bismuth (Bi), indium (In), silver (Ag), copper (Cu), cadmium (Cd), and antimony (Sb) added.

2. Depending on which element is added, we can adjust the properties of the alloy, like lowering the melting point.
3. Alloys commonly used for electrical soldering are 60/40 Sn-Pb, which melts at 188 °C (370 °F), and used principally in electrical/electronic work.
4. While mechanical soldering is used by plumbers for making mechanical connections, electrical soldering is the process by which electronic components are connected to the circuit board using a filler material to form the joint between them.