LECTURER'S NOTE

ON

ELECTRICAL ENGINEERING MATERIALS

(THEORY – 4)

FOR

3RD SEMESTER, ELECTRICAL ENGINEERING

(AS PER SCTE&VT SYLLABUS)

PREPARED BY

ER. JAYAKANTA MALLICK

LECTURER IN ELECTRICAL ENGG.

Conducting Materials

1. **Introduction**

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

2. **Classification of Electrical Materials**

- **Materials used in the electrical engineering field are classified basing on their properties and applications.**
  - a. Conductor materials.
  - b. Resistor materials.
  - c. Insulating materials.
  - d. Semiconductor materials
  - e. Magnetic materials
  - f. Refractory materials
  - g. Structural materials.
- **Classification of Materials Based on Atomic Structure**

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

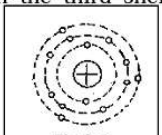


Fig 2.1

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

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

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

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

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

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

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

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

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

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

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

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

The second one is called ***covalent bond***. In this bond, the atoms of the materials having 4 or more valency electrons share their electrons with neighbouring atoms as shown in Fig. The atoms of such materials behave as if they have full outer orbits. This gives full strength to the material and low electrical conductivity because no electrons are free to move. Certain materials allow valence electrons to become free by thermal energy. These elements are known as ***semiconductors***.

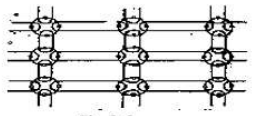


Fig 2.2

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

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

4. Conductor Materials

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

  The resistance of a material (R) depends-

  - directly to its length (L)

  -inversely to the 'X'-sectional area (A)

So, R α L / A

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

Therefore ρ = A R/L

When R= Resistance in Ohms (Ω)

L= Length in m

A= Area of cross section in m^2

ρ = resistivity or Specific resistance in Ω-m

- **Temperature Coefficient of Resistance**.

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

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

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

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

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

5. Properties of Conductors

A. *Electrical Properties*

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

B. ***Mechanical Properties***

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

C. ***Economical Factors***

1. Low Cost
2. Easily Available.

6. **Superconductor**

- Theory of super conductor.

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

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

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

a) electron-proton interaction, and

b) critical temperature.

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

7. **Characteristics of a Good Conductor Material**

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

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

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

- ***Copper***

Properties :

1. Pure copper is one of the best conductors of electricity and its conductivity is highly sensitive to impurities.
2. It is reddish-brown in colour.
3. It is malleable and ductile.
4. It can be welded at red heat.
5. It is highly resistant to corrosion.
6. Melting point is $108^{4}0$C.
7. Specific gravity of copper is 8.9.
8. Electrical resistivity is 1.682 micro ohm cm.
9. Its tensile strength varies from 3 to 4.7 tonnes/cm^2.
10. It forms important alloys like bronze and gun-metal.

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

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

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

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

- **Silver**

It is best known electrical conductor.

Properties

1. It is very costly.
2. It is not affected by weather changes.

3. It is highly ductile and malleable.

4. Its resistivity is 165 micro ohm cm.

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

- **Aluminium**

Properties:

1. Pure aluminium has silvery colour and lustre. It offers high resistance to corrosion. Its electrical conductivity is next to that of copper.

2. It is ductile and malleable.

3. Its electrical resistivity is 2.669 micro ohms cm at 20^0C.

4. It is good conductor of heat and electricity.

5. Its specific gravity is 2.7.

6. Its melting point is 658^0C.

7. It forms useful alloys with iron, copper, zinc and other metals.

8. It cannot be soldered or welded easily.

Uses : Overhead transmission line conductor, busbars, ACSR conductors. Well suited for cold climate.

- **Steel**.

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

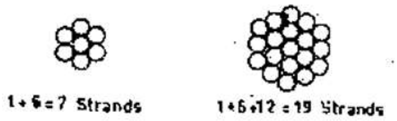
- **Bundled Conductors & Underground Cables**.

Conductor Materials for Overhead Lines : Electrical and Mechanical Properties

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

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

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



Copper conductor used for transmission is hard-drawn copper.
Properties.

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

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

Properties :

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

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

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

Cable

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

1.10.2 Required Properties of Cables.

1. High insulation resistance.

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

3. Low discharge current.

4. Sufficient strength for mechanical handling and cable laying.

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

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

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

8. Available in right quantity and at low rate.

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

10.High Resistivity Materials and their applications

- **Tungsten**

Properties :

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

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

- **Carbon**.

Carbon is mostly available as graphite which contains about 90% of carbon. Amorphous carbon is found in the form of coal, coke, charcoal, petroleum, etc.

Electrical carbon is obtained by grinding the raw carbon materials, mixing with binding agents, moulding and baking it.

Properties :

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

- **Platinum**

Properties :

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

Applications:

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

- **Mercury**

Properties:

1. It is good conductor of heat and electricity.
2. It is a heavy silver-white metal.

3. It is the only metal which is liquid at room temperature.

4. Its electrical resistivity is 95.8 micro hom cm.

5. Oxidation takes place if heated beyond 300^0C in contact with air or oxygen.

6. It expands and contracts in regular degrees when temperature changes.

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

Short Questions

Q: What is ACSR?

A: ACSR stands for Aluminium Conductor Steel Reinforced.

Q: Write the alloys of copper.

A: Alloys of copper are bronze, brass.

Q: Write the composition of brass.

A: Composition of brass are copper and zinc.

Q: Why the stranded conductors are used?

A: Stranded conductors are used to reduce proximity and skin effect.

Q: Write the name of the liquid metal.

A: The liquid metal is mercury.

Q: Give any application of superconductive material.

A: Superconductive materials are used in the field of bio magnetic.

Long Questions

Q: Write short note on steel.

Q: write the properties and use of tungsten.

Q: Write the use of platinum as a conducting material.

Q: Explain the effect of temperature on resistivity.

Q: Write short note on super conductivity.