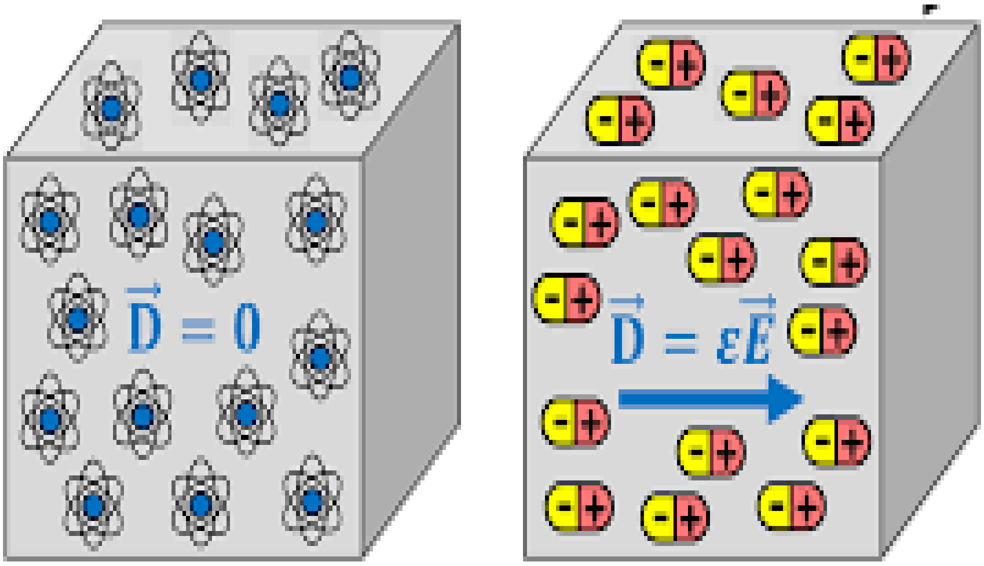
BHADRAK ENGINEERING SCHOOL & TECHNOLOGY
(BEST), ASURALI, BHADRAK

Electrical Engineering Material

(Th- 04)

(As per the 2019-20 syllabus of the SCTE&VT, Bhubaneswar, Odisha)



Third Semester

Electrical Engg.

Prepared By:*Er. M.K.Jena& Er.D.P Moharana*

ELECTRICAL ENGINEERING MATERIAL

CHAPTER-WISE DISTRIBUTION OF PERIODS & MARKS

Sl.No.	Chapter No.	Topic	Periods as per Syllabus	Expected Marks
01	01	Conducting materials	16	20
02	02	Semiconducting materials	10	20
03	03	Insulating materials	09	15
04	04	Dielectric materials	08	10
05	05	Magnetic materials	08	20
06	06	Material for special purposes	09	15
TOTAL			**60**	**110**

CHAPTER-1
CONDUCTING MATERIALS

Learning Objectives:

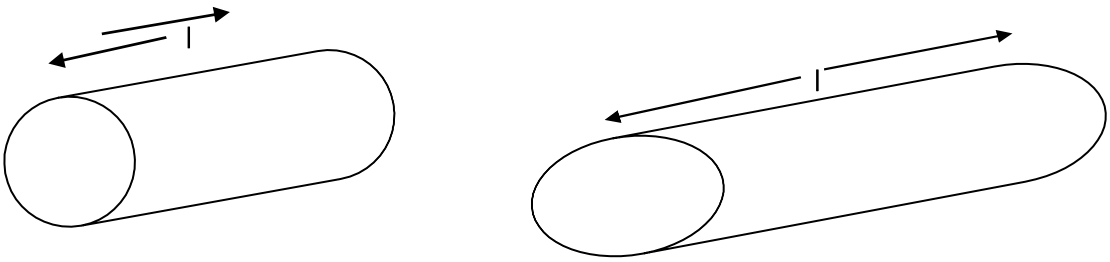
1. 1 Introduction
1. 2 Resistivity, factors affecting resistivity
1. 3 Classification of conducting materials into low-resistivity and high resistivity materials
1. 4 Low Resistivity Materials and their Applications. (Copper, Silver, Gold, Aluminum, Steel)
1. 5 Stranded conductors
1. 6 Bundled conductors
1. 7 Low resistivity copper alloys
1. 8 High Resistivity Materials and their Applications (Tungsten, Carbon, Platinum, Mercury)
1. 9 Superconductivity
1. 10 Superconducting materials
1. 11 Application of superconductor materials

1. 1 Introduction:

Conducting materials which must be good conductors of electricity, characterized by a large electrical conductivity and a small electrical resistance serve to carry current in electrical equipment. Conducting materials can further be divided into two groups namely materials of low resistivity and materials of high resistivity.

1.2 Resistivity, factors affecting resistivity: -

The resistance R offered by a conductor depends on following factors.



Smaller l
Larger A
Low R

larger l
Smaller A

Greater R

i) Various directly as its length l.
ii) Various inversely as the cross-section A of the conductor.
iii) It depends on the nature of the material.
iv) It also depends on temperature of the conduction.

Mathematically – R α l/A or $R = \rho \frac{l}{A}$, Where ρ is a constant and is known as its specific resistance or resistivity. The factor in the resistance which takes into account the nature of the material is the resistively.

The factors affecting resistivity are

i) Nature of the material
ii) Temperature

If temperature increases, resistivity of pure metals also increases. But resistivity of insulators decreases. Hence insulators are said to possess a negative temp. Co-efficient of resistance.

1.3 Classification of Conducting materials into Low-Resistivity and High Resistivity material: -

Low resistivity materials are employed for making conductors for all kinds of windings required in electrical machines, apparatus and devices, as well as for transmission and distribution of electrical energy. The fundamental requirements to be met by low resistivity materials are

i. The least possible temp coefficient of resistance.
ii. Adequate mechanical strength in particular, high tensile strength.

Low resistivity conducting materials are Copper and its alloys like cadmium copper, chromium copper, Brass, Bronze and its alloy like phosphorus Bronze, Beryllium Bronze etc.

High resistivity materials have properties like the low temperature coefficient of resistance, high melting point and no tendency for oxidation. They must be ductile and should have high mechanical strength. High resistivity materials consist of Manganin, constantan or Eureka, platinum,nichrome,tungsten,carbon and Mercury.

1.4 Low Resistivity materials and their applications-

Copper: -Due to its high conductivity and reasonable cost, copper is most widely used metal for electrical purposes. It is nonferrous, nonmagnetic (diamagnetic) metal. It possesses several advantageous properties such as given below: -

1. It is a ductile metal. It can be easily drawn into thin bars and wires. Hence it is very useful for making cables,strands and conductors.
2. Its ultimate tensile strength is high enough which makes it substantially strong to sustain mechanical loads.
3. Its melting point is sufficiently high that makes it suitable for use at high temperature also.
4. When exposed to atmospheric environment, it forms a protective layer of Copper Oxide(CuO). Thus, the Copper is highly resistant to corrosion which is a desired properly for bare/open overhead conductors.

Types of Copper: -

Copper is available in two distinct forms.These are

1) Annealed Copper
2) Hard drawn Copper

Annealed Copper is more ductile than the hard drawn copper. It is used as power cables, Winding wires for electrical machines and transformers.
Hard drawn copper possesses high mechanical strength. It is suitable for overhead transmission wires and bus-bars etc.

Silver: -It is a diamagnetic material. It possesses the highest electrical conductivity of any element and the highest thermal conductivity of any metal. The metal occurs naturally in its pure, free form, as an alloy with gold and other metals. Silver metal is used industrially in electrical contacts and conductors. Silver is very ductile, malleable (slightly harder than gold). Its greater cost has prevented it from being widely used in place of copper for electrical purposes. In radio frequency engineering, particularly at UHF and higher frequencies, where silver plating is used to improve electrical conductivity of parts.
Silver is the best conductor of heat and electricity of any metal in the periodic table. It is used incurrency, Jewellery & silverware, Dentistry (Dental filling), Photography and electronic, mirrors and optics. silver and silver alloys are used in the construction of high-quality musical wind

instruments of many types. Silver is used to make solder and brazing alloys. The medical use of silver includes its incorporation into wound dressings and its use as an antibiotic coating in medical devices. It is used in clothing or shoes.

Gold: -Symbol of Gold is Au and its atomic number is 79. It is a diamagnetic material. It is a dense, soft,malleable and ductile material. It is a dense, soft, malleable and ductile material with a bright yellow colour. Beside its wide spread monetary and symbolic functions, gold have many practical uses in dentistry, electronics and other fields. Its high malleability, ductility, resistance to corrosion and most other chemical reaction, and conductivity of electricity has led to many uses, including electric wiring,colored grass production etc. Gold readily creates alloys with many other metals.These alloys can be produced to modify the hardness and other metallurgical properties. Gold is a good conductor of heat and electricity and reflects infrared radiation strongly. Chemically it is unaffected by air, moisture and most corrosive reagents and is therefore well suited for use in coins and jewellery and as a protective coating on other more reactive metal. However it is not chemically inert. Gold is yellow colour. It is used in monetary exchange, investment, jewellery, medicine, industry, electronics & commercial Chemistry.

Aluminium: -Its conductivity is lower to that of copper, but it is cheaper than copper. It is nonferrous, weak magnetic (Paramagnetic)metal of white colour.

- It is a light weight metal.
- It is a ductile metal by Virtue of which it can be easily drawn into thin bars and wires. Therefore, aluminium is very useful for making cables, strands and conductors.
- Its ultimate tensile strength is sufficiently high which is lower than copper. Therefore, is does not find favour in making winding for transformers, motors.
- Under atmospheric exposure, it forms a protective layer over its surface. This layer is of aluminium Oxide that makes aluminium corrosion resistant.
- Itcanbeeasilysolderedwhichisanessentialrequirementinwiringandotherconnections.
- Pure aluminium is a very soft metal. But when alloyed with alloying elements like Si, Mg, Ni, Co etc, it becomes hard and tough.

Types of Aluminium: -

1. Rolled aluminum
   (i) Hot rolled
   (ii) Cold rolled
2. Hard drawn aluminum

Application: -

1) Overhead transmission line
2) Domestic wiring
3) Busbars
4) Rotor bars of squirrel cage induction motor

Steel: - Steel is an alloy of Iron and other elements including carbon. The following elements are always present in steel: carbon, manganese, Phosphorus, Sulphur, Silicon and traces of Oxygen, nitrogen and aluminium. Steel with increased carbon content can be made harder and stronger than iron, but such steel is also less ductile than iron. Steel is also distinguishable from wrought iron, which can contain a small amount of carbon, but it is included in the form of slag inclusion. To inhibit corrosion, atleast 11% chromium is added to steel so that a hard oxide forms on the metal surface, this is known as Stainless steel. Iron and steel are widely used in the construction of roads, railways, other infrastructures, appliance and buildings. Even those with a concrete structure employ steel for reinforcing. In addition, it sees wide spread use in major appliances and car. Despite growth in usage of aluminum, it is still the main material for car bodies. Steel is used in a variety of other construction materials such as bolts, nail and screws. Other common applications including shipbuilding, pipeline transport, mining, offshore construction, aerospace, white goods, heavy equipment etc.

1.5 Stranded Conductors: -Stranded conductors are made by twisting the thin wires of smaller cross-section. Wires of each layer are then laid helically around the wires of other layer. This process is called stranding. Stranding is done in opposite directions for successive layers i.e. if the wires of one layer are twisted in C.W. direction then the wires of next layer are twisted in A.C.W. direction. In this way stranding is done for different layers. Stranded conductors can be of two different designs

1) Circular stranded conductor
2) Compact circular strandedconductor

In the former type the strands are circular in cross section, while in the latter type it iselliptical. Circular stranded conductors are generally used for single phase applications. The Compactcircular stranded conductors are used for 3ϕ applications and in making core cables. The compactcircular stranded conductors are made by compacting the circular stand by means of pressing themthrougha setofdiesandrollers.

Specifications: -Stranded conductors are specified as 19/2.50, 37/2.06 etc. First numbers 19, 37 etc.Indicate the total number of wires in a stranded conductor, and the second numbers 2.50, 2.06etc.Indicate the diameter of each wire in millimeter.

1.6 Bundle conductors: -A bundle conductor is a conductor made up of two or more conductors called the subconductor per phase in close proximity compared with the spacing between phases. The sub conductors of a bundle conductor are separated from each other by aconstant distance verifying from 0.2m to 0.6m depending upon designed voltage and surrounding condition throughout the length of the line with the help of spacers. It has several advantages such as

a. Reduced corona loss and radio interference.
b. Reduced losses there by giving higher transmission efficiency.
c. Higher charging current
d. Lesser Inductance per phase
e. Higher capacitance resulting in increase in the maximum power transfer capacity.These conductorsareusedin400KVtower.

1.7 Low resistivity copper alloys:-Several alloys of copper also fall in thecategory of lowresistivity conducting materials. Main among them is brass and bronze. Brass is basically an alloy ofcopper and zinc, while bronze is an alloy of copper and tin. But they are prepared with the addition ofotherelements also.

Brass: -It is an alloy of copper containing 40% Zn. Its conductivity is lower than that of copper. It has high tensile strength and is fairly resistant to corrosion. It can be easily pressed a desired shape and size,can be drawn into wires, and can be easily brazed. Brasses are widely used in following application.

1.	Plugpoints	->	Socketoutlet
2.	Lampholders	->	Fuseholder
3.	Switches	->	Knifeswitches

Bronze: -It has a composition of 10% Sn in 90% Cu. It conductivity is lower than that of pure copper. Bronze components are generally made by forging process. It is corrosion resistant and possesses high strength. Different types of bronze are generally used in following applications.

1.Phosphor bronze for making springs,bushings etc.
2.Cadmium bronze for making commutator segments.

1.8 High resistivity materials and their application: -

High resistivity materials can be divided into 3groups. The first group consists of materials employed in electrical measuring instruments (standard, substandard etc) and in making standard resistances and resistance boxes. The second group consists of materials fromwhich resistance elements are made for all kinds of rheostats and similar control devices. In the thirdgroup are materials suitable for making high temperature elements for electric furnaces, heatingdevices andloading rheostats. All these materials should have high resistivity, low temp. Co-efficient of resistance, high melting point, high ductility, high mechanical strength and no tendency for oxidation e.g. manganin, constantan, nichrome, Tungsten, carbon etc.

Tungsten: -I)HardsteelW74->Transitionmetal

II) Resistivity twice that of aluminium

III) Can be drawn into very thin wires for making filaments

IV) In the atmosphere of inert gas (Nitrogen, argon etc.) or in vacuum, tungsten can be readily worked at temperature like 2000°C and even higher.
It is paramagnetic.

Uses-

1.This material is used in electronic and vacuum engineering used as filament in incandescent lamps such as the electrodes, heaters, spring etc.
2.The tungsten filament is made in straight, coiled or coiled coil form.
3.It is extremely resistant to the destructive acting forces.

Carbon: -It is a diamagnetic material. There are several allotropes of carbon of which the bestknown are graphite, diamond and amorphous carbon, Diamond is highly transparent, while graphite is Opaque and black. Diamond has a very low electrical conductivity, while graphite is a very good conductor. In the human body carbon is these cond. most abundant element by mass after Oxygen.
Carbon remains solid at higher temperatures than the highest melting point metals such as tungsten.

Uses: -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 currents and contacts of certain classes of d.c. switchgear which are subjected to arcing.

Platinum(pt.$_{78}$):-It is a paramagnetic material. It is a dense, malleable, ductile, precious, gray white transition metal. Transition metals are ductile and malleable platinum is more ductile than gold, silver and copper, thus being the most ductile ofpuremetals. But gold is still more malleable than platinum. It does not oxidize at any temperature. Pure platinum is slightly harder than pure iron. The metal has an excellent resistant to corrosion and high temperature and has stable electrical properties. All of these characteristics have been used for industrial applications.

Uses: -

1) The most common use of platinum is as a catalyst in chemical reactions.
2) It is used as a precious metal. Platinum finds use in jewellery.
3) In the laboratory, platinum wire is used for electrodes; platinum pans. Platinum based anodes are used in ships, pipelines.

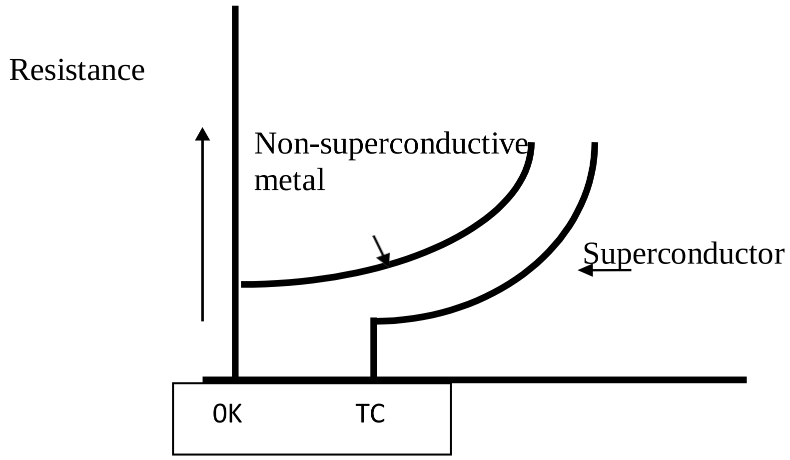
Mercury:-Hg_{80}

It is diamagnetic material. Mercury is the only metal that is liquid at standard conditions fortemperature and pressure. It is a heavy, silvery white metal. As compared to other metals, it is a poorconductor of heat, but a fair conductor of electricity. Mercury does not react with most acids such as dilute sulphuric acid.Mercury finds use in the following main applications.

i. Gas filled tubes
ii. Mercury arc rectifiers
iii. Thermometers
iv. Extraction of Precious metals
v. As liquid contact material in electrical switches.

1.9 Superconductivity: -

There are some metals and chemical compounds whose resistivity becomes zero when theirtemperature is brought near 0^0k(-273^0C). At this stage such metals or compounds are said to haveattained super conductivity. E.g. Mercury becomes superconducting at approx. 4.5^0k(-268.5^0C). Thetransition from normal conductivity to superconductivity takes place abruptly, it occurs over a verynarrow range of temperature about 0.05^0k. The temperature at which the transition takes placefrom the stateof normal conductivity to that of the super conductivity is called the transition temperature



1.10 Superconducting materials:

Superconductors are classified into the following categories.

1. On the basis of working temperature
   I. Low temperature superconductors (LTS)
   II. High temperature superconductors (HTS)

2. On the basis of kind of material
   I. Metallic superconductors(MS)
   II. Inter metallic compound superconductors.
   III. Ceramic superconductors. (CS)
   IV. Alloy superconductors.

3. On the basis of application
   I. Magnetic grade superconductors.
   II. Nonmagnetic grade superconductors.

4. On the basis of penetration of magnetic lines of force.
   I. Type I or ideal superconductors.
   II. Type II or hard superconductors.

1.11 Applications of superconductors materials: -

Currently superconductors are used in the following important applications.

1. Switching elements.
2. Flipflop devices.
3. Small cryotrons.
4. Very strong magnets.
5. Magnetic detectors.
6. Resonance imaging etc.

POSSIBLE SHORT TYPE QUESTIONS WITH ANSWER

Q1 Mention the factors which affect the value of resistivity of a material. (W-22)

Ans- The factors affecting resistivity are:

i. Temperature.
ii. Alloying
iii. Mechanical Stressing.

Q2.What happens to the resistivity if temperature increases? (S-19)

Ans. If temperature increases, resistivity of pure metal also increases.

Q3.Which material possesses the highest electrical conductivity of any element?

Ans. Silver possesses the highest electrical conductivity of any element.

Q4. What is ACSR? Where is it used? (S-19, W-20,22)

Ans-ACSR is aluminium conductor steel reinforced. It is used in transmission line.

Q5.What is the advantage of using bundle conductor in EHT line? (W-19)

Ans. .

Current carrying capacity increases

Corona loss is less

Less radio interference occurs.

Q6.What is stranding?

Ans. Stranded conductors are made by twisting the thin wires of smaller cross-section. Wires of each layer are then laid helically around the wires of other layer.

Q7.What is superconductivity? Give few examples of superconducting material?(S-18,19)

Ans. There are some metals and chemical compounds whose resistivity becomes zero when their temperature is brought near 0°K. At this stage such metals or compounds are said to have attained superconductivity. example- Mercury becomes superconductor at approx. 4.5°K.

Q8. What do you mean by resistivity and state its SI unit?(W-20,21)

Ans. Resistivity is the electrical resistance of a specific specimen of the material of unity length and cross-sectional area. Unit of resistivity is Ohm-meter.

Q9. Name the materials used in making (W-21)

i. **Elements of a filament lamp.**
ii. **Resistors for loading rheostat.**

Ans. The material used in making elements of filament lamp is tungsten and resistors for loading rheostat is constantan and manganin constantan is an alloy of copper-nickel.

Q10. Name the conducting material which is generally used in plug points, socket outlets; switches and lamp holders . State two properties of this material should possess for such applications.

Ans. Brass is a conducting material i.e generally used in plug points, socket outlets, switches and lamp holders. Two properties are:

i. It has high tensile strength but has lower conductivity than copper.
ii. It is weldable and solderable and fairly resistant to corrosion.

POSSIBLE LONG TYPE QUESTIONS

Q1. State the advantage and disadvantage of aluminium as compared to copper when used as conductor of electricity. (S-15,19)

Q2.Describe briefly about stranded conductor.

Q3.Write short note on bundle conductor.

Q4.Which are the materials of high resistivity and their application? (W-20)

Q5.Explain Superconductivity with description of different types of superconductors. Give the application of superconductors. (S-19,W-22)

Q6. Discuss the physical, electrical and mechanical properties of copper and its use as engineering material. Where it can be substituted by aluminium and with what limitation.(W-22)

Q7. Explain the low resistivity materials and their applications in details.(W-21)

Q8. Write the application of superconductor materials.(W-16,17,20,21)

Q9. What is resistivity of conductor materials? A resistance wire of length 1 meter and diameter 0.08mm has a resistance of 95.5ohms. Calculate the resistivity of the wire material.(W-22)

CHAPTER-2
SEMICONDUCTING MATERIALS:

Learning Objectives: -

2. 1 Introduction
2 . 2 Semiconductors
2 . 3 Electron Energy and Energy Band Theory
2 . 4 Excitation of Atoms
2 . 5 Insulators, Semiconductors and Conductors
2 . 6 Semiconductor Materials
2 . 7 Covalent Bonds
2 . 8 Intrinsic Semiconductors
2 . 9 Extrinsic Semiconductors
2 . 10 N-Type Materials
2 . 11 P-Type Materials
2 . 12 Minority and Majority Carriers
2 . 13 Semi-Conductor Materials
2 . 14 Applications of Semiconductor materials
2.14.1 Rectifiers
2.14.2 Temperature-sensitive resisters or thermistors
2.14.3 Photoconductive cells
2.14.4 Photovoltaic cells
2.14.5 Varistors
2.14.6 Transistors
2.14.7 Hall effect generators
2.14.8 Solar power

2.1 Introduction: -

Semiconductors are those materials whose conductivity lies between conductor and insulator.

2.2 Semiconductors: -

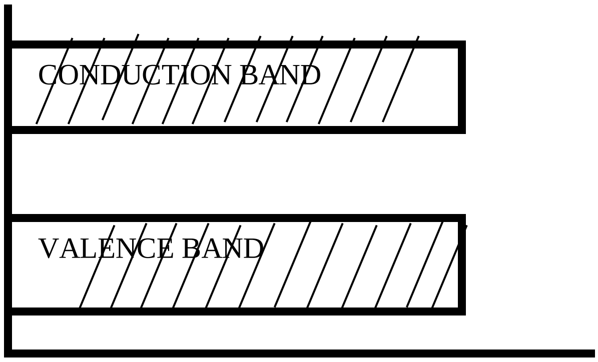
In semiconductor valency band is filled and conduction band is empty. Semiconductors are substances with properties somewhere between them. ICs (Integrated circuit) and electronic discrete components such as diodes and transistors are made of semiconductors. Common elemental semiconductors are Silicon and Germanium. Semiconductors become essential for many electronic appliances as well as for social infrastructure that support our everyday life.

2.3 Electron Energy & Energy band theory-

Electrical engineering Materials are classified into four categories i.e.

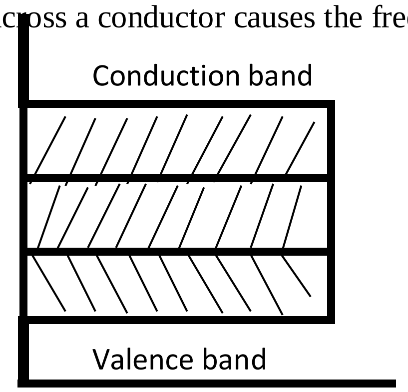
1. Insulator
2. Conductor
3. Semiconductor
4. Magnetic Materials

Insulator:-

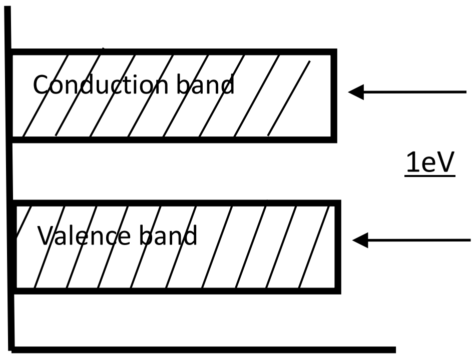


Insulators are those substances which do not allow the Passage of electric Current through them. In terms of energy band, the valence band is full while the conduction band is empty. Further the energygap between valence and conduction band is very large. ~15ev.
For this reason, the electrical conductivity of such materials is extremely small and may be regarded as nil under ordinary condition

Conductors: -. Conductors are those substances which easily allow the passage of electric current through them. In termsof energy band, the valence and conduction bands overlap each other. Due to this Overlapping, a slight p.d. across a conductor causes the free electrons toconstitute electric current.



Semiconductors: -Semiconductors are those substances whose electrical Conductivity lies in between conductors and insulators. In terms Of energy band, conduction band is almost empty. Further the energy gap between Valence and conduction band is very small. Therefore comparatively smaller electric field is required to push the electrons from the Valence band to conduction band. In short a semiconductor has



a) Almost full valence band
b) Almost empty conduction band.
c) Small energy gap between valence & conduction bands.

2.4 Excitation of atoms -Excitation, in physics, the addition of a discrete amount of energy (called excitation energy) to a system such as an atomic nucleus, an atom or a molecule. When that results in its alteration ordinarily from the condition of lowest energy to that of higher energy.

Insulators, Semiconductor and conductor-The substance in which current does not flow is called insulator. Insulators are negative coefficient of resistance. It means that when temperature increases, resistance decreases. The substance whose conductivity lies between conductor and insulator is called semiconductor. Semiconductors are negative coefficient of resistance. The substance in which current flows easily is called conductor. Conductors are positive temperature coefficient of resistance. It means when temperature increases, resistance increases.

2.6 Semiconductor materials:-

Sl.No.	Element	Symbol	Atomic No,
1	Boron	B	5
2	Carbon	C	6
3	Silicon	Si	14
4	Germanium	Ge	32
5	Phosphorus	P	15
6	Arsenic	As	33
7	Antimony	Sb	51
8	Sulphur	S	16
9	Selenium	Se	34
10	Tellurium	Te	52
11	Iodine	I	53

2. 7 Covalent Bonds:-A covalent 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. For many molecules, the sharing of electrons allows each atom to attain the equivalent of a full valence shell, corresponding to a stable electronic configuration. In organic chemistry, covalent bonds are much more common than ionic bonds.

Atomic orbitals (except for s orbitals) have specific directional properties leading to different types of covalent bonds. Sigma (σ) bonds are the strongest covalent bonds and are due to head-on overlapping of orbitals on two different atoms. A single bond is usually a σ bond. Pi (π) bonds are weaker and are due to lateral overlap between p (or d) orbitals. A double bond between two given atoms consists of one σ and one π bond, and a triple bond is one σ and two π bonds.

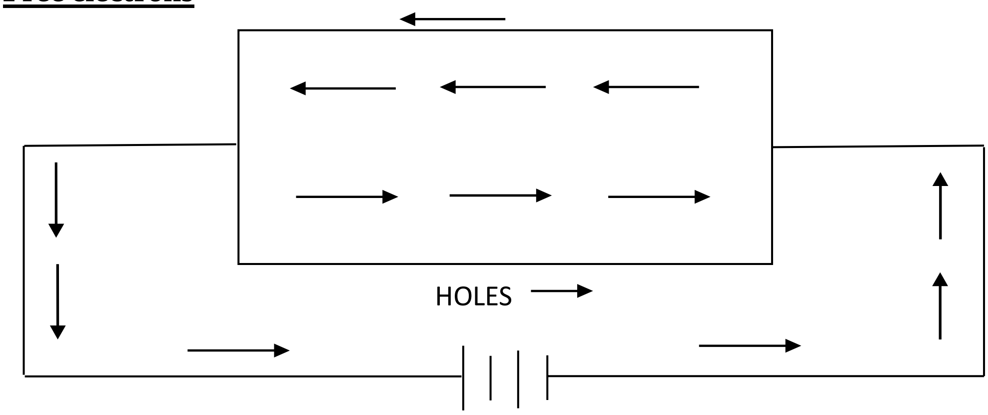
Covalent bonds are also affected by the electro negativity of the connected atoms which determines the chemical polarity of the bond. Two atoms with equal electro negativity will make no polar covalent bonds such as H–H. An unequal relationship creates a polar covalent bond such as with H−Cl. However polarity also requires geometric asymmetry, or else dipoles may cancel out resulting in a non-polar molecule.

Modified Lewis structures with 3e bonds

Nitric oxide Dioxygen

<u>2.8 Intrinsic Semiconductors</u>:-A semiconductor in an extremely pure form in known as intrinsic semiconductor.

<u>Free electrons</u>



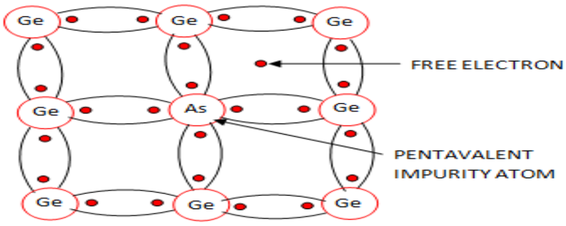
When electric field is applied across an intrinsic semiconductor, the current conduction takes place by two processes: by free electrons and holes as shown in figure. The free electros are produced due to breaking up of some covalent bonds by thermal energy. At thesame time holes are created in the covalent bond under the influence of electric field, conduction through the semiconductor is by both free electron and holes. Therefore, the total current inside the semiconductor is the sum of currents due to free electrons and holes. Current in the external wire is fully electronic. Referring to figure holes being positively charged move towards the negative terminal of supply. As the holes reach the negative terminal, electrons enter the semiconductor crystal hear the terminal and combine with holes, thus cancelling them. At the same time the loosely held electrons near the positive terminal are attracted away from their atoms into the positive terminals.

<u>2.9 Extrinsic Semiconductor: -</u>When a small amount of suitable impurity is added to a semiconductor, it is then called impurity or extrinsic semiconductor is known as doping. The process of adding impurity is to increase either the number of free electrons or holes in the semiconductor crystal. If a pentavalent impurity (having 5 valence electrons) is added to the semiconductor, a large no of free electrons are produced in the semiconductor. On the other hand addition of trivalent impurity (having 3 valence electrons) creates a large no. of holes in the semiconductor crystal. Depending upon the type of impurity added, extrinsic semiconductors are classified into

1. N-type semiconductor
2. P-type semiconductor

2.10 N-Type Materials: -

When a small amount of pentavalent impurity is added to a pure semiconductor, it is known as n- type semiconductor. Such impurities which produce n-type semiconductor are known as donor impurities because they donate or provide free electrons to the semiconductor crystal.

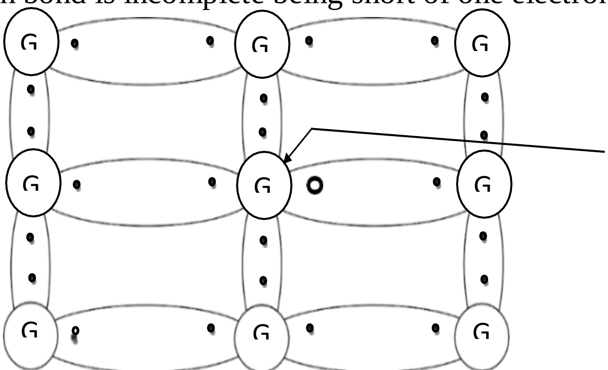


To explain the formation of n-type semiconductor, consider a pure germanium crystal. We know that Germanium atom has four valence electrons. when a small amount of pentavalent impurity like arsenic is added to germanium crystal, a large no. of free electrons become available in the crystal. Arsenic is pentavalent. Its atom has five valence electrons. An arsenic atom fits in the germanium crystal in such a way that its four valence electrons form covalent bonds with four germanium atoms. The fifth valence electron of arsenic atom finds no place in covalent bonds and is thus free. Therefore, for each arsenic atom added, one free electron will be available in germanium crystal. Though each arsenic atom provides enough atoms to supply millions of free electrons. It is this predominance of electrons over holes that it is called n-type semiconductor. N stands for negative.

2.11 P- type Materials: -

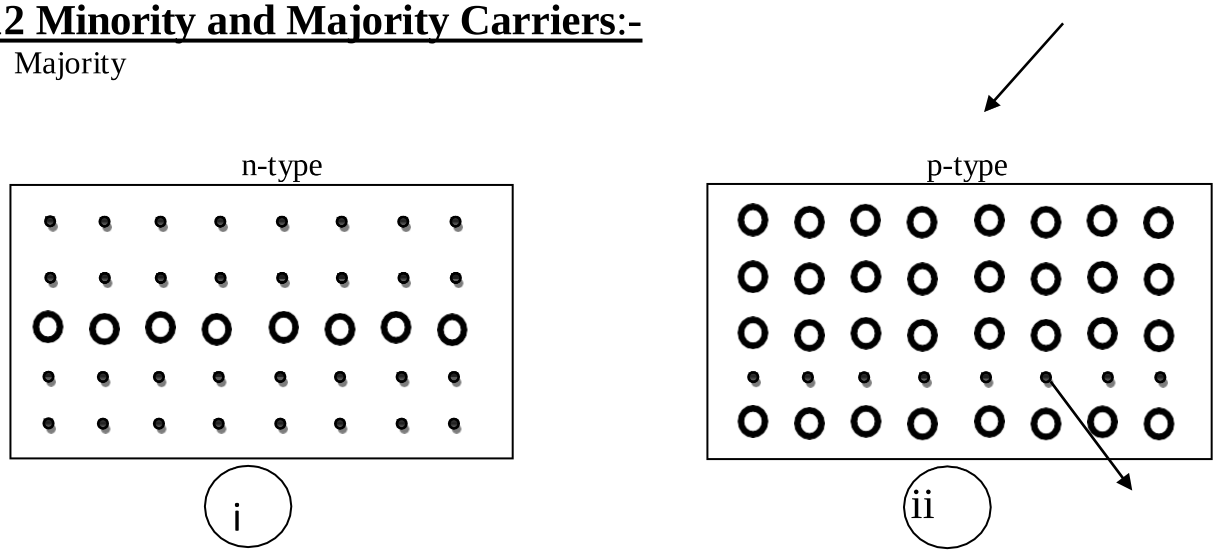
When a small amount of trivalent impurity is added to a pure semiconductor, it is called p-type semiconductor. Trivalent impurities are gallium and indium. Such impurities which produce p-type semiconductor are known as acceptor impurities because the holes created can accept the electrons.

To explain the formation of p-type semiconductor, consider a pure germanium crystal. When a small amount of trivalent impurity like gallium is added to germanium crystal, there exists a large number of holes in the crystal. Gallium is trivalent i.e. its atom has three valence electrons. Each atom of gallium fits into germanium crystal but now only three covalent bonds can be formed. It is because three valence electrons gallium atom can form only three single covalent bonds with three germanium atoms. In the fourth covalent bond, only germanium atom contributes one valence electron while gallium has no valence electron to contribute as all the three valence electrons are already engaged in the co-valent bonds with neighboring germanium atoms. In other words , fourth bond is incomplete being short of one electron.



This missing electron is called a hole. Therefore, for each gallium atom added, one hole is created. A small amount of gallium provides millions of holes. It is due to the predominance of holes over free electrons that it is called p-type semiconductor (p-stands for positive).

2.12 Minority and Majority Carriers:-



An n-type material has a large number of free electrons and a small number of holes as shown in figure .The free electrons in this case are considered majority carries-since the majority portion ofcurrent in n- type material is by the flow of free electrons and the holes are minority carriers.

Similarly in a p-type material, holes outnumber the free electrons as shown in figure. Therefore holes are the majority carriers and free electrons are the minority carries.

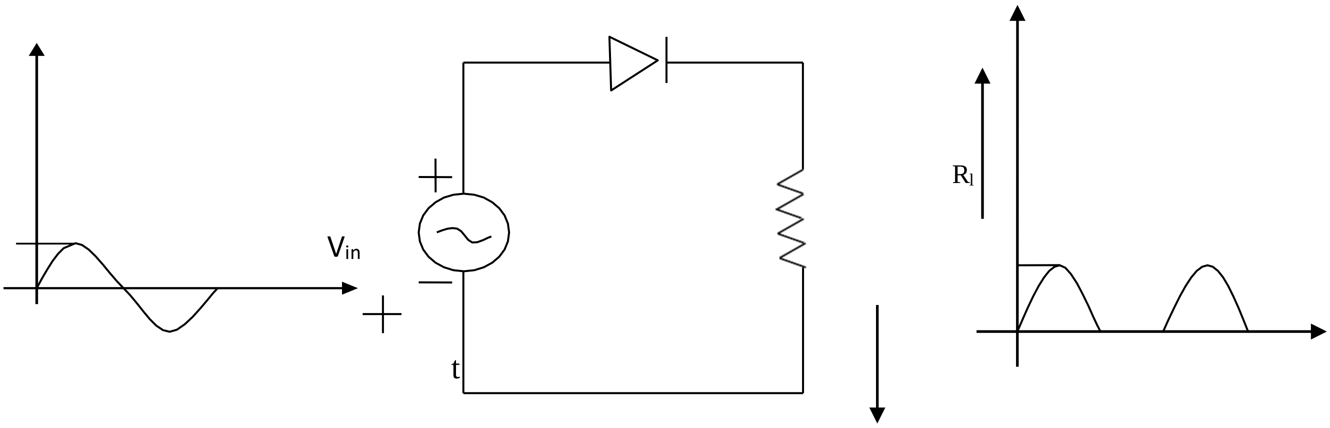
2.13 Semiconductor materials: -

Sl.No.	Element	Symbol	Atomic No,
1	Boron	B	5
2	Carbon	C	6
3	Silicon	Si	14
4	Germanium	Ge	32
5	Phosphorus	P	15
6	Arsenic	As	33
7	Antimony	Sb	51
8	Sulphur	S	16
9	Selenium	Se	34
10	Tellurium	Te	52
11	Iodine	I	53

2.4. Application of semiconductor materials: -

Semiconductor materials are applied in devices like transistors and lasers. Power semiconductor devices are discrete devices or integrated circuits intended for high current or high voltage applications. Power integrated circuits combine IC technology with power semiconductor technology; these are sometimes referred to as smart power devices. Some of the most important semiconductor devices are diodes, transistors and thyristors. Semiconductors find wide applications because of their compactness, reliability and low cost. They can handle a wide range of current and voltage. Semiconductor devices are around us. Theycan be found in just every commercial product we touch, from the family car to the pocket calculator Semiconductor. Laser is the acronym for Light amplification by stimulated emission of radiation. Semiconductor devices are contained in television sets, portable radios, stereo equipment and much more. Industrial control systems (such as those used to manufacture automobiles) and automatic telephone exchanges also use semiconductors. Even today heavy-duty versions of the solid state rectifier diode are being used to convert large amounts of power for electric railroads of many different applications for solid state devices, space systems, computers, data processing equipment are some of the largest consumers.

2.14.1 Rectifiers:-



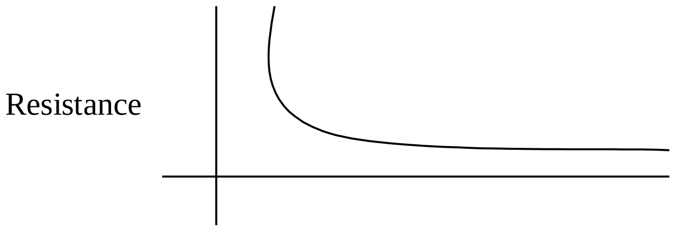
The a.c. input voltage to be rectified; the diode and load R_L are connected in series. The d.c. output is obtained across the load. During the positive half cycle of a.c. input voltage, diode isforward biased and conducts current in the circuit.

The result is that positive half cycle of input voltage appears across R_L. However, during the negative half cycle of input a.c. voltage, the diode becomes reverse biased. Therefore diode does not conduct and no voltage appears across load R_L .

The result is that output consists of positive half cycles of input a.c. voltage while the negative half cycles are suppressed. In this way, crystal diode has been able to do rectification.

2.14.2 Temperature Sensitive resistors or thermistors: -

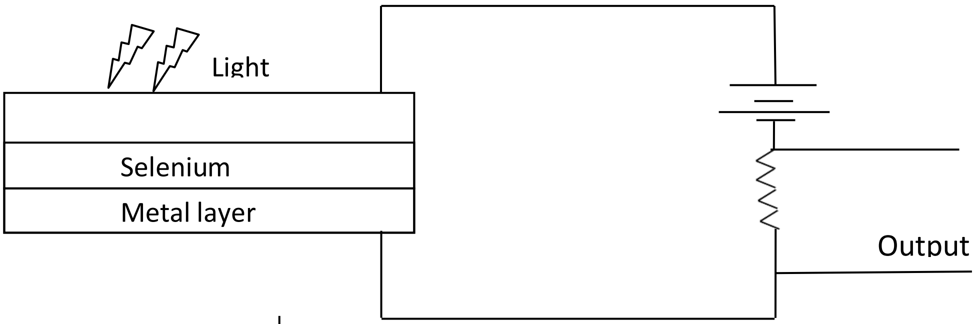
Thermistors are also called the thermal resistors as the resistance of a thermistor varies as a function of temperature. Thermistors are essentially semiconductor devices that behave as resistors with high negative temp. Co-efficient.

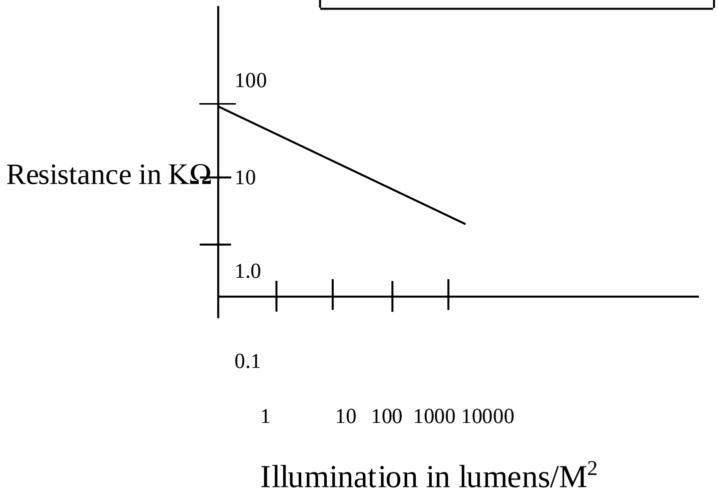


<u>Applications: -</u> These are cheaper in cost and highly sensitive devices. It is used in

i. Measurement of temperature
ii. Measurement of difference of two temperature
iii. Control of temperature
iv. Temperature compensation
v. Thermal conductivity measurement
vi. Measurement of gas composition
vii. Measurement of flow

<u>2.14.3 Photoconductive cells</u>: A Photo conductive cell is a device whose resistance decreases with increasing incident light intensity. The device works when light falls on it at high intensity making electrons to jump into the conduction band thus causing it to conduct electricity.





The electrical resistance of a semiconductor depends on the intensity of the incident light . A photoconductive cell works on the above principle.

A Photoconductive cell Consists of a thin transparent surface film of some metal, Which is placed on thin layer of semiconductor like selenium, which in turn is placed over a metal layer of iron.

A high p.d. is applied across surface film and iron layer when light of suitable frequency falls on the transparent film, the electrical resistance of selenium layer decreases.

This changes the current flowing in the circuit. Photo conductive cells are also called photo resistors.

Applications: -

I. Camera exposure control
II. Density meter
III. Automatic headlight dimmer
IV. Night light control
V. Street light control

2.14.4 Photovoltaic Cells :- A Photovoltaic cell (also called solar cell) is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect. It is a form of photoelectric cell (in that its electrical characteristics – e.g. current voltage, or resistance – vary when light is incident upon it) which, when exposed to light, can generate and support an electric current without being attached to any external voltage source. The operation of a photovoltaic cell requires three basic attributes.

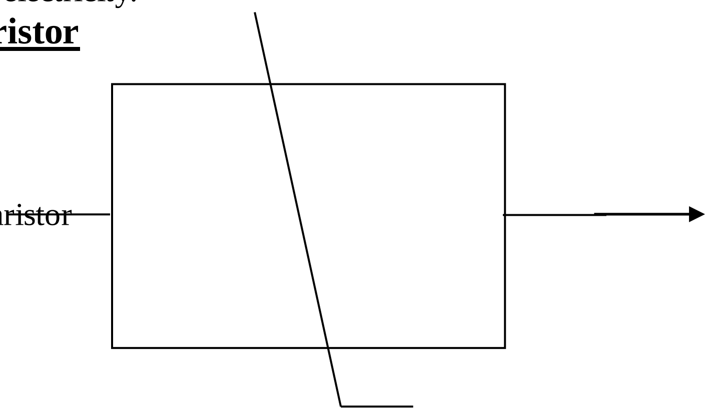
- The absorption of light, generating either electron-hole pairs .
- The separation of charge carriers of opposite types
- The separate extraction of those carries to an external circuit. When light shines on the cell, it creates an electric field across the layers.

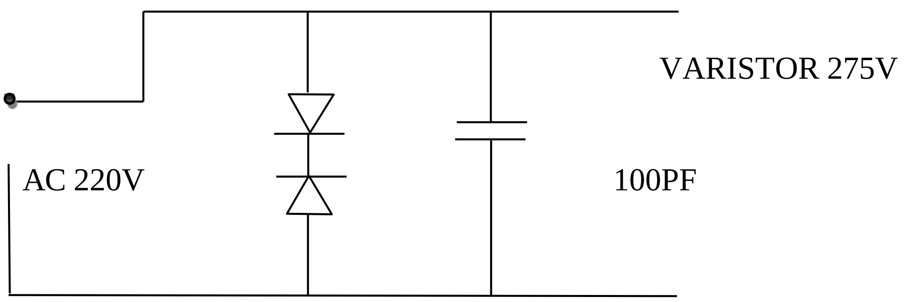
The solar cells work in three steps.

- Photos in sunlight hit the solar panel and are absorbed by semiconducting materials, such as silicon. Photons striking the cell pass through the thin p-doped upper layer and are absorbed by electrons in the lower N-layer causing formation of conduction electrons and holes. The depletion zone potential of PN junction then separates these conduction holes and electrons causing a difference of potential to develop across the junction
- Electrons (negatively charged) are knocked loose from their atoms, causing an electric p.d. current starts flowing through the material to cancel the potential and this electricity is captured. Due to the special composition of solar cells, the electrons are only allowed to move in a single direction.
- An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity.

2.14.5 Varistor

Symbol of varistor





A varistor is an electronic component with a diode like non linear current voltage characteristic. Thename is a portmanteau of variable resistor. Varistors are often used to protect circuits against excessive transient voltages. A varistor is also known as voltage dependent resistor.

A varistor's function is to conduct significantly increased current when voltage is excessive. Only non ohmic variable resistors are usually called varistors. Other ohm types of variable resistor include the potentiometer and the rheostat.

Their resistance decreases when the voltage increases. In case of excessive voltage increases, theirresistance drops dramatically.

Applications :-

i. Telephone and other communication line protection
ii. Power supply protection
iii. Electronics equipment protection

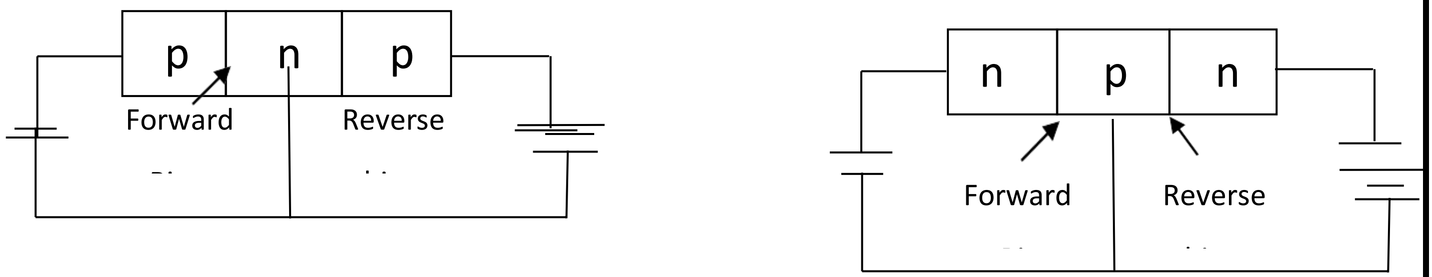
2.14.6 Transistor:- A transistor consists of two PN Junctions and three terminal device. Accordingly, there are two types of transistors, namely

- n-p-n transistor
- p-n-p transistor

Naming the transistor terminals----

Emitter Base Collector

Emitter Base Collector

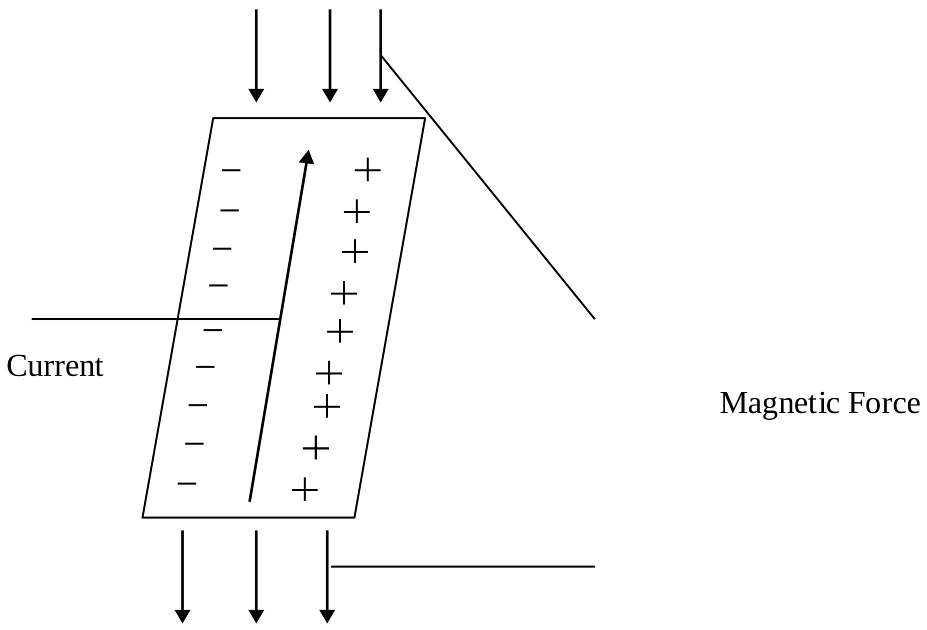


Emitter: - The section on one side that supplies charge carriers is called the emitter. The emitter is always forward biased w.r.t. base so that it can supply a large no. of majority carriers. The emitter p-type of p-n-p transistor is forward biased and supplies hole charges to its junction with the base. Similarly, n-type of n-p-n transistor has a forward bias and supplies free electrons to its junction with the base.

Collector: - The section on the other side that collects the charge is called the collector. The collector is always reverse biased. The collector p-type of p-n-p transistor has a reverse bias.

Base: - The middle section which forms two p-n junctions between the emitter and collector is called base. The base –emitter junction is forward biased allowing low resistance for the emitter circuit. The base collector junction is reverse biased provides high resistance in collector circuit.

2.14.7 Hall Effect generator:-When a current carrying electrical conductor is placed in a magnetic field, a voltage sometimes develops between one side of the conductor and the other. For this to happen, the magnetic lines of forcemust be perpendicular, or nearly perpendicular to the line containing the conductor. The voltage then appears at right angles to the magnetic lines of force. It the conductor ids a strip and the magnetic lines of force perpendicular to the strip, then the voltage will appear between apposite edges of the strip. This ig called Hall Effect.



The electric field intensity given as e is described by the formula e= Kim
Where "i" is the current ,m is magnetic field strength, and k is hall constant.

2.14.8 Solar power: - Solar power is the conversion of sunlight into electricity . This is done by using solar panels, which are large flat panels made up of many individual solar cells. It is most often used in remote locations.

Every day light hits your roof's solar panels with photos (particles of sunlight). The solar panel converts those photons into electrons of direct current electricity. The electrons flow out of the solarpanel and into an inverter and other electrical safety devices. The inverter coverts that DC power (commonly used in batteries) into alternating current or AC power.

Solar cells are small, square shaped panel semiconductor made form silicon and other conductive materials. When sunlight strikes a solar cell, chemical reactions release electrons, generating electric current. Solar cells are called photovoltaic cells or PV cells.

Merits of Semiconductor electrical engineering: -

1. Semiconductor devices are very compact and portable. Therefore, circuits using semiconductordevices are very compact and are portable.
2. The devices are operated with relatively low voltages; therefore, power consumption is less.
3. Ductility is a solid material's ability to deform under tensile stress, this is often characterized by thematerial's ability to be stretched into a wire

malleability, a similar property is a material’s ability to deform under compressive stress; this is often characterized by the material’s ability to form a thinsheet (without breaking) by hammering.

4. These devices have almost unlimited life unless they are subjected to wrong voltages.

POSSIBLE SHORT TYPE QUESTIONS WITH ANSWER

Q1. What is intrinsic semiconductor? 2020(N)old
Ans. A semiconductor in an extremely pure form is known as intrinsicsemiconductor

Q2. What is extrinsic semiconductor? 2019(S)BP,2019(S) new

Ans. When a small amount of suitable impurity is added to a pure semiconductor, itis then called impurity or extrinsic semiconductor.

Q3. What is a photovoltaic cell (PV Cell)? W-17,(W-20,21)

Ans. A photovoltaic cell is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect

Q4. What is thermistor? 2016, w-17,2019(S)new

Ans. Thermistors are also called the thermal resistors as the resistance of athermistor varies as a function of temperature.

Q5. What is photoconductive cell?

Ans. A photoconductive cell is a device whose resistance decreases with increasingincident light intensity.

Q6. What is Varistor? w-18,2020(W)old

Ans. A varistor is an electronic component with a diode like non- linear currentvoltage characteristic.

Q7. Mention what number of electrons in the valence ring makes the best conductor and the best insulator.(W-22)

Ans. Normally a conductor has three or less valence electrons makes the best conductor and insulator has five or more valence electrons.

Q8. State the use of semiconductor in industrial application.(W-22)

Ans. Semiconductors are employed in the manufacture of various kinds of electronic devices including diodes, transistors and integrated circuits. Such devices have found wide application because of their compactness, reliability, power efficiency and low cost.

Q9. What is N-type semiconductor? Give an example.(W-21)

Ans. When a small amount of Pentavalent impurity is added to a pure semiconductor, it is known as N-type semiconductor. Such impurities which produce n-type semiconductor are known as donor impurities.

Example: When arsenic(As) bonds with germanium, then n-type semiconductor is formed.

POSSIBLE LONG TYPE QUESTIONS

Q1. Explain with the help of energy band diagram N-type semiconductor & P-type semiconductor? 2018(old),2019 W/N ,2022W

Q2. Explain photovoltaic cell?

Q3. Briefly describe Hall effect generator? ,2018(S),(W-19,20)

Q4. Differentiate between intrinsic & extrinsic semiconductor.2020(W)

Q5. Describe about the electron energy and the energy band theory briefly.(W-21)

Q6. Write short note on (W-20,21)

i. Hall effect generator

ii. Solar power

CHAPTER :-3
INSULATING MATERIAL

Learning Objectives:

3. 1 Introduction
3. 2 General properties of Insulating Materials
3.2.1 Electrical properties
3.2.2 Visual properties
3.2.3 Mechanical properties
3.2.4 Thermal properties
3.2.5 Chemical properties
3.2.6 Ageing
3.3 Insulating Materials – Classification, properties, applications
3.3.1 Introduction
3.3.2 Classification of insulating materials on the basis physical and chemical structure
3.4 Insulating Gases
3.4.1 Introduction
3.4.2 Commonly used insulating gases

3.1 Introduction: -

Insulating materials are those materials in which current does not flow.

3.2 General properties of insulating material: -

The general properties are

- Electrical properties
- Visual properties
- Mechanical properties
- Thermal properties
- Chemical properties

3.2.1 Electrical properties-

- Insulation resistance
- Dielectric strength (Breakdown voltage)
- Dielectric constantiv- Dielectric loss

Insulation resistance-: The resistance offered to the flow of electric current through thematerial is called insulation resistance. It is of two types

i-Volume insulation resistance
ii-Surface insulation resistance

Factors affecting insulation resistance:

Temperature-: As the temperature of the insulating material rises, its insulation resistancekeeps on falling.

Moisture-: Insulation resistance is reduced if the material absorbs moisture .so insulatingmaterial should be non-hygroscopic.

Applied voltage-: Applied voltage also affects insulation resistance.

Dielectric strength-: Dielectric strength is the minimum voltage which when applied to an insulating material will result in the destruction of its insulating properties. Electrical appliances are designed to operate with in a defined range of voltage. If the operating voltage is increased gradually at some value of voltage, the breakdown of insulating materialwill occur. The property which attributes to such type of breakdown is called the dielectric strength. Dielectric strength of mica is 80kv/mm. It means if the voltage applied across 1mm thick sheet of mica becomes 80kv, mica will lose its insulating properties.

Dielectric constant-: The ratio of capacity of storing the electric charge by an insulating material to that of air is called dielectric constant of the material. Every insulating material has the property of storing electric charge Q when a voltage v is applied across it. The charge is proportional to the voltage applied and we get Q=CV. Where C is the capacitance of the capacitor.

Dielectric loss-: Electrical energy absorbed by the insulating material and dissipated in the form of heat when an alternating voltage is applied across it is called dielectric loss. When a perfect insulation is subjected to alternating voltage it is like applying like alternating voltage to a perfect capacitor .In such a case there is no consumption of power. Factors affecting dielectric loss-: Temperature, Moisture, voltage applied.

3.2.2 Visual properties-:The following are the visual properties of insulating materials which are not of much importance as regarding the performance but come handy for distinguishingof cables
. Appearance and colour

3.2.3 Mechanical properties-:

Density-: Electrical insulations are used on the basis of volume and not weight. Insulating material of low density is especially suitable for small portable equipment.

Viscosity-:It is of importance in liquid dielectric. Uniform viscosity provides uniform electrical and thermal properties

Moisture absorption-: Water lowers the electrical resistance and dielectric strength. With its absorption certain chemical and mechanical effects may result
e.g. swelling, corrosion

Hardness of surface-: Hardness of surface enables the dielectric to resist surface scratching and abrasion

Surface tension-: In liquid dielectric low surface tension is desirable as it causes greater wetting of the electrical components and thus gives better cooling.

Uniformity-: Dielectric should be uniform throughout as it keeps the electrical losses as low as possible and electric stresses uniform under high voltage differences.

3.2.4 Thermal properties-:

Heat resistance-: This is the general property of insulating material to withstand temp.variation with in desirable limits without damaging its other important properties. If aninsulator has favorable properties at ambient temperature but if it is not able to retain these, it is not a good insulator. The insulator which is capable of withstanding higher temp. without deterioration of its other properties can be used for operation for such higher temp.

Permissible temperature rise-: There is always some recommended operating temperature for an insulator. The operating temp. has a bearing on the life of the concerned apparatus.

Effect of overloading on the life of an electrical appliance-: Insulators can withstand overloading within permissible limits for short period of time. Continuous overloading ultimately results in the breakdown of insulating material. If the involved insulating material is able to withstand the higher voltages, the change will cause increase of dielectric loss that will increase heat generation.

Thermal conductivity-: Heat generated due to 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 temp. rise because of effective heat transfer through it to the atmosphere

3.2.5 Chemical properties-:

Resistance to external chemical effects-: Insulating materials should be resistant to oils or liquids, acids. The materials should not undergo oxidation and hydrolysis even under adverse condition Resistance to chemicals in soils-: Cables laid in the soil can deteriorate by the action of chemicals in soils. So, it should be resistant to chemicals in soils

Effect of water and tropical tests-: Water directly lowers electrical properties such as electrical resistance and dielectric strength. The water may be transmitted through an outside coating and cause damage inside, it may be directly absorbed by an insulating material, it may cause a chemical change of insulation itself, or it may drastically lower the surface resistance of insulator.

3.2.6 Ageing-: Ageing reduces the insulation resistance. As age of insulating material is increased, the insulation resistance decreases. Ageing reduces the dielectric strength of the insulating material.

3.3Essential properties of insulating materials-

An ideal insulating material should possess

1. Dielectric strength as good as that of mica
2. Mechanical strength as good as that of steel
3. Crushing resistance as good as that of granite
4. Fire proofing qualities as good as that of silica
5. Chemical inertness equal to that of platinum.
6. Surface finish like that of ebonite
7. Low dielectric loss
8. Viscosity
9. Porosity
10. Solubility
11. High melting point
12. High flash point
13. High thermal conductivity
14. Non volatility
15. Low thermal expansion
16. High resistance to heat

Classification of insulating material :-

1. Fibrous materials-Wood ,paper ,textile industry
2. Insulating liquids-Mineral insulating oils ,vegetable oils
3. Not resinous material-Asphalts and waxes
4. Impregnated fibrous material-impregnated paper
5. Ceramics-Porcelain, alumina
6. Mica and its products
7. Asbestos and its products
8. Glass-fibre glass
9. Insulating resins and their products
10. Laminates and adhesives
11. Enamels and varnishes

Application of insulating material

Insulating material for transformer

Part to be insulated	Insulating Material
Air cooled and oil cooled transformer	Fibrous Material
For tapping the coil of air cooled transformer	Cotton or oil cambric
Insulation between core and coils and also between	Synthetic resins

Insulating material for machines

	Part to be insulated	Insulating material
1.	DC and ac motor and generator for industrial Installations	Laminated wool, Varnished paper
2.	Insulation of commutators	Mica
3.	For insulating terminals of H.V. machines	Porcelain

Insulating materials for electronic equipment

	Equipment	Insulating material
1.	TV and radio receiver	Synthetic resin, Paper, press board
2.	Medical electronics	Synthetic resin, Paper and oil
3.	Computer	Synthetic resin Paper Bonded paper

3.3.1Introduction: -

In Insulating material current does not flow easily.

3.3.2Classification of insulating materials on the basis of physical and chemical structure :-

Insulating material on the basis of their physical and chemical structure may be classified in various categories

1. Fibrous material
2. Impregnated fibrous materials
3. Non resinous materials
4. Insulating liquids
5. Ceramics
6. Mica and mica products
7. Asbestos and asbestos products
8. Glass
9. Natural and synthetic rubbers
10. Insulating resins and their products
11. Laminates, adhesives, enamels and varnishes

3.4 Insulating gases-:

3.4.1 Introduction:- Insulating gases are used both as an insulant and heat transfer medium. The major problem they entail are

i. Temperature instability
ii. Abnormalities in dielectric behavior at high pressure
iii. Fire hazard

3.4.2 Commonly used insulating gases-:

The insulating gases on the basis of dielectric strength .dielectric loss ,Chemicalstability and corrosion etc. may be classified as follows

1. Simple gases
   a. Air
   b. Nitrogen
   c. Hydrogen
   d. Helium
2. Oxide gases
   a. Carbon dioxide
   b. Sulphur dioxide
3. Hydrocarbon gases
   a. Methane
   b. Ethane
   c. Propane
   d. Freon gases
4. Electronegative gases
   a. Sulphur hexafluoride
   b. CH_2Cl_2

POSSIBLE SHORT TYPE QUESTIONS WITH ANSWER

Q1. What is ageing?2019(W/N)

Ans. Ageing reduces the insulation resistance. As age of insulation material is increased, the insulation resistance decreases.

Q2. What is the effect of porosity?

2018(N),2020(N)

Ans. Porosity is a measure of the void(empty)spaces in a material and fraction of volume of voids over the total volume between 0&1 or as a percentage between 0% and 100%

Q3. What is dielectric loss?2020(W)

Ans- Electrical energy absorbed by the insulating material and dissipated in the form of heat when an alternating voltage is applied across it is called dielectric loss.

.**Q4. What are the visual properties?**

Ans. The visual properties are appearance and colour

Q5. Write the name of the commonly used insulating gases
2018(old)

Ans. The commonly used insulating gases are

i. Simple gases
ii. Oxide gases
iii. Hydrocarbon gases
iv. Electronegative gases

Q6. State an application of (W-21)

i. Teflon
ii. PVC insulating material

Ans. Teflon is used as a coating in non-stick cookware products such as pots and pans. The application of PVC insulating material is in cables, wires.

POSSIBLE LONG TYPE QUESTIONS

Q1. Write classification of insulating materials on the basis of physical andchemical structure? 2018(old)

Q2. Classify insulating materials on the basis of physical and chemical structure. 2018(old)

Q3. Write down electrical properties? 2015(S)

Q4. Write down mechanical properties?

Q5. What are the factors affecting insulation resistance?2020,2021(W)

Q6. Explain the mechanical properties affecting the selection of insulator in brief.(W-21)

Q7. Describe about natural and synthetic rubber and their applications.(W-21)

Q8. Name the different classes of varnishes available. Describe what are epoxy resin varnishes and silicon resin varnishes.(W-22)

Q9. What insulating material would you select for the following? Also mention 10 reasons for the selection: 2022(W)

a) Flexible wire
b) High voltage cable
c) Low voltage cable
d) Fuse holder
e) Commutator in DC machines

CHAPTER: 4
DIELECTRIC MATERIALS

Learning objectives:

4.1 Introduction

4.2 Dielectric Constant of Permittivity

4.3 Polarization

4.4 Dielectric Loss

4.5 Electric Conductivity of Dielectrics and their Break Down

4.6 Properties of Dielectrics.

4.7 Applications of Dielectrics

4.1 Introduction: -

Insulators also known as dielectrics are very poor conductors of heat and electricity. However, they allow movement of some electrons at high temperature causing a small flow of current. Dielectrics are characterized by their high specific resistance, negative temperature coefficient of resistance andlarge insulation resistance. The insulation resistance is affected by moisture, temperature, applied electric field and age of dielectrics. Dielectric materials may be solid, liquid or gas.

4.2.Dielectric constant of permittivity: -

The dielectric constant ε_r (or relative permittivity) is a measure of polarization of dielectric materials. It is the ratio of absolute permittivity ε and the permittivity of free spaceand is given by $\varepsilon_r = \varepsilon / \varepsilon_0$. Here ε_r is dimensionless. The value $\varepsilon_r = 1$ for air or vacuum $\varepsilon_r > 1$ for solids, its value for diamond is 5.68,for silicon is 12,for mica is 8 and for germanium is 16.Dielectric constant is influenced by frequency of applied field and temperature.

4.3.Polarization: -

Insulating materials are subjected to different types of electric fields. These maybe static field, alternating and direct current fields, impulsive and frequency switching field. Their properties are different under different field. Therefore, we first need to study insulating properties of dielectrics in static field to understand polarization. The polarization is the sum of total dipole moments produced within the solid on application of electric field. It occurs because on application of an electric field to a dielectric, the positive charges are displaced towards negative end of the field while negative charges are displaced towards the positive end. Hence local dipoles are produced in the dielectric due to this displacement. These dipoles keep their moments and are called dipole moment. Total dipole moments within the volume of a solid is called polarization P.

The electric flux density D and the electric field strength E at a point in a dielectric material are related by

$D/E = \varepsilon_0 \varepsilon_r$

$D = \varepsilon_0 \varepsilon_r E$ 01

By adding and subtracting $\varepsilon_0 E$, we may write $D = \varepsilon_0 \varepsilon_r E + \varepsilon_0 E - \varepsilon_0 E$

$= \varepsilon_0 E + \varepsilon_0 E(\varepsilon_r - 1)$

$= \varepsilon_0 E+P$ ……………………………02

Value of D from Eqn (1) is put in Eqn (2)

$\varepsilon_0 \varepsilon_r E= \varepsilon_0 E + P$ $\mathbf{P= \varepsilon_0 \varepsilon_r E- \varepsilon_0 E}$

The polarization process is affected by time, frequency of the applied field and temperature.

4.4.Dielectric loss: -

While calculating the dielectric losses usually only the volume leakage current is taken consideration. Of course, there is loss of certain amount of power due to surface leakage current but this power is primarily dissipated as heat into the surrounding atmosphere and this loss does not influence the heating of the dielectric in most of cases. The dielectric power loss(P) may be given by $P=2\pi fcv^2 \tan\theta$

Where V=voltage

C=Actual capacitance of the dielectric

Tan(θ)=Dielectric loss tangent

According to the above equation, the dielectric power loss is directly proportional to the frequency. The dielectric losses are greater at a high frequency and this makes it more difficult to select insulating material for high frequency applications.

Classification of dielectric material:-

1. **S**olid insulating materials: Bakelite, PVC, rubber, mica, porcelain, glass

2. Liquid insulating materials: Asphalt, transformer oil, purified water, SF_6

3. Gaseous insulating materials:

a) Electropositive gases such as N_2
b) Electronegative gases such as H_2
c) mixture gases such as air
d) Hydrocarbon gases such as CO_2, SO_2
e) Oxide gases such as CH_4,C_2H

4.5 Electric conductivity Of dielectrics and their breakdown-:

The voltage per unit thickness that can be sustained by an insulating material before its breakdown is called as dielectric strength. A good insulating material possesses high dielectric strength. Dielectric breakdown occurs on account of following factors. These are called as

- Intrinsic (Zener)breakdown
- Thermal breakdown
- Electrochemical breakdown
- Discharge breakdown
- Defect breakdown

Intrinsic breakdown: -It occurs when electrons in the valance band cross the forbidden gap under the influence of applied voltage and enter into conduction band. A large conduction current and extremely high local field is created in the process. This failure is called as Zener breakdown. Intrinsic breakdown can happen at a lower voltage if impurities are present in the dielectric material.

Thermal breakdown:- It occurs at high temperature due to poor heat dissipation and hence accumulation of non-dissipated heat produced by electrical energy. Failure occurs by melting and can be avoided if heat dissipation is more than heat generation.

Electrochemical breakdown:-It takes place when the leakage current increases due to large mobility of ions at raised temperature. The dielectrics convert into their oxides and insulating resistance decreases due to this chemical action. Breakdown of rubber is an example of this kind.

Discharge breakdown: It occurs due to the presence of gas bubbles in the solid and their bombardment on application of applied field. Gaseous atoms get ionized at lower potential than the solid atoms and hence cause deterioration

Defect breakdown:-It occurs on the surface of dielectric material due to detrimental effects of moisture on the cracks and pores. Fire proof silica, high strength mica and other chemically inert materials are used to provide good surface finish.

4.6 Properties of Dielectrics:-

Insulating materials are a very poor conductor of electric current. Dielectrics have no loosely bound electrons and so no current flows through them. When they are placed in an electric field, the positive and negative charges within the dielectrics are displaced minutely in opposite direction, which reduces the electric field within the dielectric. Example of dielectric include glass, plastics and ceramics.

4.7 Applications of Dielectric:-

The function of dielectric is to store energy. Capacitor is the most common example in which use of dielectrics is made. Depending upon the type of dielectric used, the capacitors may be grouped into following categories

1. **Capacitors that use vacuum, air or other gas as dielectrics**-: These capacitors are used in applications where the energy loss (in the capacitors) must be small and where the value of capacitances needed is not very large. Dielectric losses in these capacitances are very small.
2. **Capacitors that use mineral oil as dielectric**-: These are used in applications where a large value of capacitance is required and where a small amount of dielectric loss can be tolerated.
3. **Capacitors which use a combination of solid and liquid dielectrics-**
   : Oil impregnated paper dielectric is used for making capacitors of large values of small size. Such capacitors are required in the applications where precision is not so important buta high value capacitance is required. power factor correction in electric power distributionsystem
4. **Capacitors which use solid dielectric such as glass, mica-:** These are employed in laboratories as standard capacitors. Mica is commonly used as solid dielectric in making standard capacitor.Dielectric loss of mica is very small.

POSSIBLE SHORT TYPE QUESTIONS WITH ANSWER:

Q1. What do you mean by dielectric constant? What is the dielectric constant of air? 2018(Old), 2021(W)

Ans. Dielectric constant is the ratio of absolute permittivity € and permittivity of free space $€_0$ and is given by $€_r=€/€_0$.

- Dielectric constant of air is 1.00059.

Q2. What is dielectric strength? 2019(S)(BP)

Ans. The maximum voltage that can be applied to a given material without causing its breakdown usually expressed in volt or kv per unit of thickness is known as dielectric strength.

Q3. Write the application of dielectrics. 2018(S)

Ans. Dielectric materials are solid e.g. Porcelain, Mica, glass, plastic and the oxide of various metals. Some liquids and gases can serve as good dielectric material. Dry air is an excellent dielectric and is used in variable capacitor. Distilled water is a fair dielectric.

Q4. Which is liquid insulating material?

Ans. Asphalt, transformer oil, purified water, Sulphur hexafluoride

Q5. What are the factors affecting dielectric strength of insulating material? 2020,2021(W)

Ans. The factors affecting dielectric strength are temperature, moisture and voltage applied.

Q6. State the factors which affect the dielectric loss of an insulating material. 2022(W)

Ans. The factors affect the dielectric loss of an insulating material are :

i. Temperature ii. Humidity iii. Applied voltage iv. Frequency

Q7. State the difference between a dielectric material and an insulating material as regards their functions. 2022(W)

Ans. Dielectric Material:

i. The material which allow to flow of electric current in an applied electric field is called as a dielectric material.
ii. The dielectric stores the electric charge.
iii. It has low resistive power.

Insulating Material:

i. The material which does not allow to flow of electric current in an applied electric field is called as an insulating material.
ii. The insulator does not store the electric charge.
iii. It has high resistive power.

POSSIBLE LONG TYPE QUESTIONS

Q1. Explain polarisation? 2018(New)

Q2. Write down the electric conductivity of dielectrics and their breakdown?

Q3. Write down the application of dielectrics? 2018(Old)

Q4. Write short note on dielectric material? 2018(New)

Q5. Write in brief about the Polarisation of dielectric.2020,2022(W)

Q6. Explain the electrical conductivity and the breakdown of 2021(W)

i. Gaseous dielectrics
ii. Liquid dielectrics

Q7. Explain the following:

i. Permittivity ii. Dielectric strength iii. Dielectric constant iv. Breakdown voltage v. Loss angle

CHAPTER:-5
MAGNETIC MATERIALS

Learning Objectives:

5.1 Introduction

5.2 Classification

5.2.1 Diamagnetism

5.2.2 Para magnetism

5.2.3 Ferromagnetism

5.3 Magnetization Curve

5.4 Hysteresis

5.5 Eddy Currents

5.6 Curie Point

5.7 Magneto-striction

5.8 Soft and Hard magnetic Materials

5.8.1 Soft magnetic materials

5.8.2 Hard magnetic materials

5.1 Introduction:-

Material switch can be magnetized are called magnetic Material.

Flux density (B) =φ/A=Magnetic lines of force/Area of the pole face=Flux/area

Magnetic field strength or magnetizing force (H)-: Magnetic field strength at any point in a magnetic field is numerically equal to the forced experienced by a N-pole of one Weber placed atthatpoint. Hence unit of His N/Wb

Permeability: -It is the property of a material by virtue of which it allows sit self to be magnetized. $\mu=B/H$.

5.2 Classification: -

Magneticmaterialsareclassifiedinto3types.

I. Diamagnetic material
II. Paramagnetic material
III. Ferromagnetic material

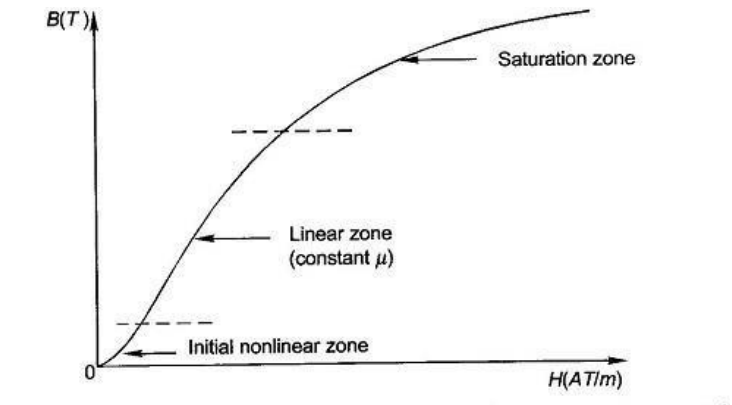
5.2.1 Diamagnetic material: -Diamagnetic materials are those materials which are repelled by the magnets e.g. antimony, Bismuth, lead, mercury, gold etc. Their relative permeability is slightly less than unity. Substance is magnetized in a direction opposite to the direction of magnetizing field.

5.2.2 Paramagnetic material: -Paramagnetic materials are those materials which are weakly attracted by the magnets. E.g. Aluminium, Platinum. Their relative permeability (μ_r) is slightly higherthan unity. They are magnetized in the direction of magnetizing field.

5.2.3 Ferro magnetic material: -Ferromagnetic materials are those materials which are strongly attracted by the magnets. e.g . iron, cobalt, nickel. Relative permeability (μr) is much higher than one.They are magnetized in the direction of magnetizing field. The properties of ferromagnetic materials are nearly similar to those of paramagnetic materials.

5.3 Magnetization Curve: -

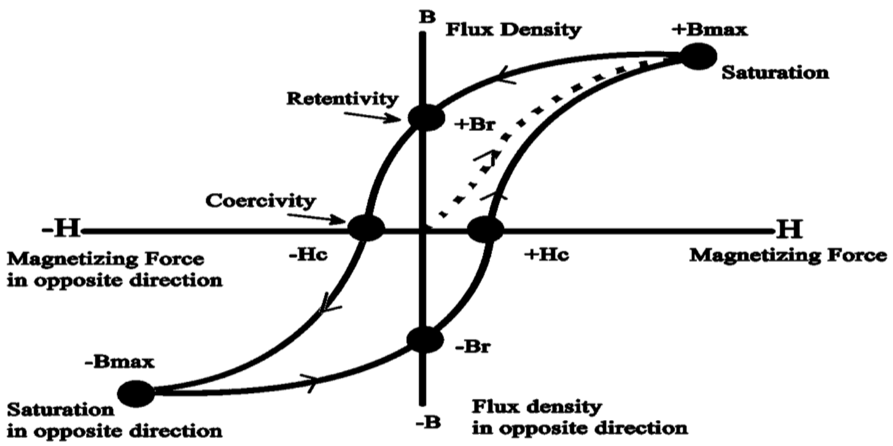
The curve plotted between magnetizing force and flux density of a ferromagnetic material is known as magnetization curve.



Typical normal magnetization curve of ferromagnetic material

Before saturation, flux density (B) increases linearly with magnetizing force (H). After saturation, the increase in B is slow till it almost ceases to increase even for very large increase in H and the curve becomes almost horizontal.

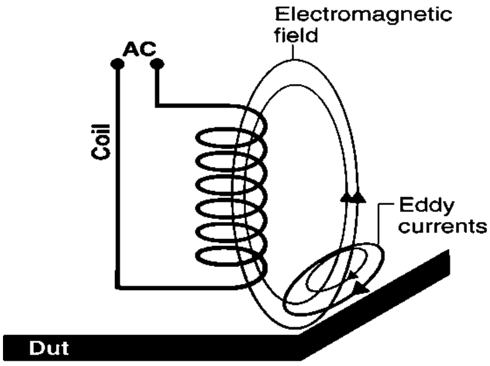
5.4.Hysteresis:-It may be defined as the lagging of magnetization or induction flux density (B) behind the magnetizing force (H).



It is seen that B always lags behind H. The two never attain zero values simultaneously. The lagging of B behind H is given the name hysteresis which literally means to lag behind. The process to which the bar is magnetizing-demagnetizing-magnetizing, some energy is wasted. This loss of energy is referred to as the hysteresis loss.

5.5 Eddy currents: -

Eddy currents are circular electric currents induced within conductors by a changing magnetic field within the conductor.



5.6 Curie point: -

As a magnetic material is heated, its molecules vibrate more violently. Obviously it is possible to partially or even completely destroy the magnetic properties of a material by heating. The temperature at which the magnetic strength reduces to zero is called curie point.

5.7 Magnetostriction: -

It has been established that when ferromagnetic materials are magnetized, a small change in dimensions of the materials take place. There is a small extension with corresponding reduction of the cross-section of the crystal of which the material is made. When subjected to rapidly alternating magnetic fields, there is a rapid and continuous extension and contraction of the materials. This is called magnetostriction. This is the major cause of hum in transformer and choke.

5.8 Soft& Hard magnetic material

5.8.1 Soft magnetic material: -Soft magnetic material can be magnetized very easily, but the magnetism induced in them is only temporary. They have a steeply rising magnetization curve. They have relatively small and narrow hysteresis loop. They are used in transformers, generators and motors. Softiron, Silicon steel, nickel-iron alloys.

5.8.2 Hard magnetic material: -Hard magnetic materials can be permanently magnetized by a strong magnetic field. They have a gradually rising magnetization curve. They have large hysteresis loop area. They are used for making permanent magnets.

e.g., Steel, Tungsten, Alnico

POSSIBLE SHORT TYPE QUESTIONS WITH ANSWER:

Q1.Define Curie point. W-17,2019(S)
Ans. It is possible to partially or even completely destroy the magnetic properties of a material by heating. The temperature at which the magnetic strength reduces to zero is called curie point.

Q2.Whatis diamagnetic material? 2020(W)
Ans. Diamagnetic materials are those materials which are repelled by the magnet.
e.g. Gold.

Q3.Whatis paramagnetic material?2018(New)
Ans. Paramagnetic materials are those materials which are weakly attracted by the magnet.

Q4.Whatis magnetostriction? 2019 W/N,2021(W),2022(W)
Ans. When the magnetic material is subjected to rapidly alternating magnetic field. there is a rapidly and continuous extension and contraction of the material. This is called magnetostriction.

Q5. What do you mean by skin effect?2018(N),2019(S)
Ans. The tendency of alternating current to concentrate near the surface of the conductor is called skin effect.

Q6.What is eddycurrent?2020,2022(W)
Ans. Eddy currents are circular electric currents induced with in conductor by a changing magnetic field within the conductor.

Q7. Name the special type of steel used for cores of power transformers. Give reasons . 2022(W)
Ans. Grain- oriented Silicon steel is a soft magnetic poly crystalline metallic alloy that is used as core material in electrical transformer cores. This type material has high permeability i.e. chosen for transformer core.

POSSIBLE LONG TYPE QUESTIONS:

Q1.Explain briefly about magnetostriction? W-17
Q2. Classify three types of magnetic materials. 2018(old)
Q3. Give the difference between soft & hard magnetic material.2019(S)N,2021(W)
Q4.Write a short note on hysteresis loop for ferromagnetic material.2020(W)
Q5. Draw and explain hysteresis loop for ferromagnetic material.2018(N),2019(S)BP,2022(W)
Q6. Explain the domain theory of ferromagnetic material briefly? 2021(W)
Q7. What are ferrites? What are their advantages over other magnetic materials? 2022(W)

CHAPTER: 6
MATERIALS FOR SPECIAL PURPOSES

Learning Objectives:

6.1 Introduction
6.2 Structural Materials
6.3 Protective Materials
6.3.1 Lead
6.3.2 Steel tapes, wires and strip
6.4 Other Materials
6.4.1 Thermocouple materials
6.4.2 Bimetal
6.4.3 Soldering Materials
6.4.4 Fuse and fuse materials
6.4.5 Dehydrating material

6.1 Introduction: -

The Materials used for special purpose are structural materials, protective materials, thermocouple materials, bimetal, soldering materials, Fuse materials, dehydrating material.

6.2 Structural materials: -

Structural materials are those which are used for the construction of various structures such as poles ,towers ,supports for transformer, circuit breaker ,foundation for rotating machines like motor and generator etc. The usual structural materials used in electrical engineering. Structures are wood, iron and steel, cement ,bricks, mortar, concrete and reinforced cement concrete(RCC).Factors to be considered while selecting a structural materialare asfollows:-

- Line voltage
- Type of place and its location Initial cost of erection
- Costs and other problem Availability of materials Transportation facilities Environmental factors.
- Future expansion consideration

6.3 Protective materials: -It is of different type

- Corrosion protection material
- Lighting protection material ,Fire protection material
- Pipe protection materials, Personal protective material
- Heat protection material
- Eye sight protection material

6.3.1 Lead: -

Lead (**Pb_{82}**) is a soft and malleable metal. Lead is used in building construction, lead acidbatteries .Lead is a bright and silvery metal .Its melting point is 600.61K. Its boiling point is2022k. It is a corrosion resistantmetal. Several lead alloys are widely used. Solder, an alloythat is nearly half lead and half tin is a material with a relatively low melting point that is usedto joinelectricalcomponents.

6.3.2Steel tapes, Wires&Strip: -

A steel tape is a tape measure that is made of steel and is marked off in a linear scale. The scale could be in inches and or centimetres. The steel tape is used for taking measurement and it is also referred to as a tapeline.

Electrical wire is the medium through which electricity is carried to and through each individual home that uses electrical power. It is made of a metal that easily conducts electricity, usually copper, in a plastic sheath called an insulator.

I. Residential wire color code-

II. Neutral wire: white

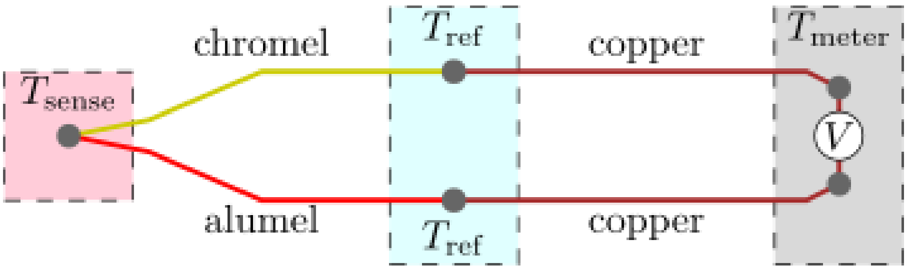
III. Ground wire(earth):Green

Electrical wire size is taken by considering AWG(American wire gauge).AWG uses a complex numbering pattern ranging from 40 to 0000 wherein 40 indicates the thinnest and 0000 refers to thickest wire size. Increasing gauge numbers give decreasing wire diameter.

Strip is a long narrow piece of a material. Small no. of wires are called strip.

6.4 Othermaterials:-

6.4.1Thermocouples & Thermocouple materials: Thermocouples are perhaps the simplest and most widely used devices for measurement of temperature. It essentially consists of two dissimilar metal wires insulated from each other but welded or brazed together at their ends forming two junctions. When heat is applied to the hot junction of two dissimilar metals, an EMF is generated which can be measured at the cold junction.



While many materials exhibit the thermoelectric effect to some degree, only a small number of pairs such as platinum-rhodium, chrome, lumen, iron-constantan are in common use.

6.4.2 Bimetal: -Bimetal refers to an object that is composed of two separate metals joinedtogether. Each metal having a different coefficient of thermal expansion. Alloys of iron andnickel with low coefficient of thermal expansion are used as one element of bimetallic strip. The other element consists of material shaving high value of coefficient of thermal expansion, e.g.iron,nickel,constantan, brassetc.. Bimetals are used as relay, thermometer, switches

6.4.3 Soldering materials: - Soldering is a process in which two or more metal items arejoined together by melting and flowing a filler metal(solder) into the joint. The filler metalhaving a lower melting point than the work piece. Soldering differs from welding in thatsoldering does not involve melting the work piece. In brazing the filler metal melts at a high temperature, but the work piece metal does not melt. There are two types of solder. hardsolder,softsolder.

Hard solder-: The tensile strength is up to 50kg/mm^2 and the melting point is higher than 400^{0}c.Their common use is for making connection in power apparatus.

Soft solder-: The tensile strength is 5.7 kg/mm^2 and melting point is up to 400^{0}c.Tin lead orlead tin solders come in this category. It is commonly used in electronics devices for soldering electrical connections.

6.4.4 Fuse& Fuse element materials: -A fuse is a short piece of metal, inserted in the circuit which melts when excessive current flows through it and thus break the circuit. The fuse element is generallymade of materials having low melting point, high conductivity and least deterioration due tooxidation e.g. silver, copper etc. It is inserted in series with the circuit to be protected. Undernormal operating condition, the fuse element is at a temperature below its melting point.Therefore, it carries the normal current without overheating. However, when a short circuit oroverload occurs, the current through the fuse increases beyond its rated value. This raises the temperature and fuse element melts, disconnecting the circuit protected by it.

The most commonly used materials for fuse element are lead, tin,copper, zinc and silver. For small currents up to 10A, tin or an alloy of lead and tin is used formaking the fuse element. For larger currents, copper or silver is employed. It is a usual practice to tin the copper to protect it from oxidation.

6.4.5 Dehydrating material: -

Silica gel-: It is inorganic chemical, colloidal, highly absorbent silica used as a dehumidifyingand dehydrating agent, as a catalyst carrier and sometimes as a catalyst. Calcium chloride and silica gel are used in dehydrating breather to remove moisture from the air entering a transformer as it breathes. Silica gel breathers are a more recent development and are replacing the calcium chloride breathers. Its main advantage is that when it becomes saturated with moisture it does not restrict breathing as does calcium chloride. Silica gel when dry is blue in colour and the colour changes to pale pink as it becomes saturated with moisture. If it is found to contain excessive moisture, it must be replaced or reconditioned.

POSSIBLE SHORT TYPE QUESTIONS WITH ANSWERS

Q1.What are the thermocouple matrials?2019(S)(new),2019(S)BP

Ans. The thermocouple materials in pair are copper-constantan and iron-constantan.

Q2.Which properties should a fuse material possess?2020(W),2021(W)

Ans. The fuse material should possess high conductivity and low melting point.

Q3.What is bimetal? 2019 W/N,2022(W)

Ans. Bimetal refers to an object that is composed of two separate metals joined together. Each metal having a different coefficient of thermal expansion.

Q4.What do you mean by soldering?

Ans. Soldering is a process in which two or more metals item are joined togetherbymeltingand flowingafillermetalinto thejoint.

Q5. State the use of steel tapes, wires and strips in electrical engg.2018(Old)

Ans. A steel tape is a tape measure that is made off steel and is marked off in a linear scale.
Electrical wire is the medium through which electricity is carried to and through.
Small no.of wires are called strips.

Q6. What do you mean by Thermocouple? Give an example of thermocouple? 2021(W)

Ans. Thermocouples are perhaps the most simple and most widely used devices for measurement of temperature. It essentially consists of two dissimilar metal wires. Example: Such as Platinum-Rhodium, Copper-Constantan& Iron- Constantan.

POSSIBLE LONG TYPE QUESTIONS:

Q1.Writedown about thermocouple? W-17

Q2.Explain about the fuse materials.2018(New)

Q3.Write about soldering materials briefly. 2020(W),2021(W),2022(W)

Q4.Write a short note about dehydrating material. 2018(Old),2019(S)BP

Q5. What are structure materials and what factors to be considered while erecting structural material?

Q6. Write short note on Silica gel? 2018,2022(W)

Q7. Explain what do you understand by fuse and fuse materials. Explain with the help of a neat sketch of cartridge fuse? 2018(S),2020(W),2021(W)