Electrical Engineering Material (EEM) - Note
Subhree Sangita Dash
(3rd sem Electrical students)

Chapter-1

Conducting Materials

Introduction :→

→ The materials which conduct electricity due to free electrons when an electric potential difference is applied across them are known as conducting materials.

→ Conducting materials are good conductors of heat and electricity.

→ Gold, silver, copper, aluminium are the examples of conducting materials.

→ Materials which allow current to pass through them easily are called conducting materials e.g. copper, aluminium etc. Conducting materials should be able to withstand high temperatures and should have minium power even when large current are passing through them.

Resistivity :→

→ It is also known as specific resistance of a material. Resistivity or specific resistance of a material may be defined as the resistance between the opposite faces of a meter cube of that material. The unit of Resistivity is ohm-meter(Ωm).

→ Resistivity is the resistance of a conducting material of unit length and having unit area of cross-section. It is a property of material and depends on nature of the material.

→ Resistivity is the electrical resistance of a conductor of unit cross-sectional area and unit length. A characteristic property of each material, resistivity is useful in comparing various materials on the basis of their ability to conduct electric currents. High resistivity designates poor conductors.

→ The symbol of resistivity is a greek letter rho(ρ), is quantitatively equal to the resistance (R) of a specimen such as wire, multiplied by its cross-sectional area (A) and divided by its length (l).

Then, we have, $R = \rho \frac{l}{A}$

$\Rightarrow \rho = \frac{RA}{l}$

where, R = Resistance in ohm(Ω).

l = length in meter (m)

ρ = resistivity in ohm-meter (Ω m).

A = Area or cross-section or the cross-sectional area in m^2.

Factors affecting Resistance :→

→ There are several factors affect the resistance of a material. These are :→
(i) The type of material (ii) its width (iii) its length and (iv) its temperature.

Factors affecting Resistivity :→

→ Factors affecting the resistivity of the electrical materials are given below :-
(1) Temperature (2) Alloying (3) Mechanical stressing
(4) Age Hardening
(5) Cold working

(1) Temperature :→ The resistivity of materials changes with temperature. Resistivity of most of the metals increase with temperature, means the metals are having positive temperature coefficient of resistance. Several metals exhibit the zero resistivity at temperature near to absolute zero. This phenomenon is called the "superconductivity."

→ The resistivity of the semiconductors and insulators decrease with increase in temperature. Means the semiconductors and insulators are having negative temperature coefficient of resistance.

(2) Alloying :→ It is a solid solution of two or more metals. Alloying of metal is used to achieve some mechanical and electrical properties.

→ The atomic structure of a solid solution is irregular as compared to pure metals. Due to which the electrical resistivity of the solid solution increases more rapidly with increase of alloy content.

→ A small content of impurity may increase the resistivity of metal considerably. Even the impurity of low resistivity increases the resistivity of base metal considerably. For example the impurity of silver in copper increase the resistivity of copper.

(3) Mechanical stressing :→ Mechanical stressing of the crystal structure of materials develops the localised strains in the material crystal structure. These localized strains disturb the movement of free electrons through the material which results in an increase in resistivity of the material.

(4) Age Hardening :→ Age hardening is a heat treatment process used to increase the yield strength and to develop the ability in alloys to resist the permanent deformation by external forces. Age hardening is also called "precipitation Hardening."

→ This process increases the strength of the alloys by creating solid impurities or precipitate.

(5) Cold working :→ It is a manufacturing process used to increase the strength of the metals.

→ Cold working is also known as "Work hardening" or "strain hardening". Cold working is used to increase the mechanical strength of the metal or the material.

Conductivity:→

→ Electrical conductivity or specific conductivity is the measure of a material's ability to conduct electric current. Conductivity is the reciprocal (inverse) of electrical resistivity.

Superconductivity:→ Superconductivity is a phenomena in certain metals and ceramics where the resistivity of the material drops to zero below a certain critical temperature i.e. known as "T_c". These temperatures are low, with most industrial superconductors below 12 K [K = Kelvin, the unit of temperature] and higher temperature ceramics just above 130K.

Classification of conducting Materials in to low-resistivity and high resistivity Materials:→

Low Resistivity Materials:→ A material with low resistivity means it has low resistance and thus the electrons flow smoothly through the material.

→ For example, copper, Aluminium, silver, gold and steel have low resistivity.

→ Good conductors have less resistivity and Insulators have high resistivity.

→ Materials having low resistivity or high conductivity are very useful in electrical engineering for manufacturing electrical engineering machines or equipments. These materials used as conductors for all kinds of winding required in electrical machines, apparatus and devices. These materials are also used as conductor in transmission and distribution of electrical energy.

High resistivity Materials :→ A material with high resistivity means it has got high resistance and will resist the flow of electrons.

→ For example, Tungsten, carbon, platinum, Mercury, have high resistivity.

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

Low Resistivity Materials and their applications :→

① Copper :→

properties :→ (a) pure copper is one of the best conductors of electricity and its conductivity is highly sensitive to impurities.

(b) It is reddish-Brown in colour.

(c) It is highly resistant to corrosion.

(d) It is malleable and ductile.

(e) It can be welded at red heat.

(f) Its melting point is 1084°c.

(g) specific gravity of copper is 8.9.

(h) Electrical resistivity is 1.682 micro ohm cm.

(i) Its tensile strength varies from 3 to 4.7 tonnes/cm².

(j) It forms important alloys like bronze and gun-metal.

uses:→ It is used in wires, cables, windings of generators and transformers, overhead conductors, busbars.

→ Hard (cold-drawn) copper conductor is mechanically strong with tensile strength 40 kg/mm². It is obtained by drawing cold copper bars into conductor length. It is used for overhead line conductors and busbars.

② Aluminium :→

properties :→ (a) Pure aluminium has silvery colour and it offers high resistance to corrosion. Its electrical conductivity is next to that of copper.

(b) It is ductile and malleable.

(c) Its electrical resistivity is 2.669 micro ohms cm at 20°c.

(d) It is good conductor of heat and electricity.

(e) Its specific gravity is 2.7.

(f) Its melting point is 658°C.

(g) It forms useful alloys with iron, copper, zinc and other metals.

(h) It cannot be soldered or welded easily.

uses:→ These are used in overhead transmission line wires, busbars, ACSR conductors.

→ It is well suited for cold climate.

③ silver :→

properties :→ (a) It is very costly.

(b) It is not affected by weather changes.

(c) It is highly ductile and malleable.

(d) Its resistivity is 1.65 micro ohm cm.

uses:→ It is used in special contacts rupturing capacity fuses, radio frequency conducting bodies, leads in valves and instruments.

④ Gold :→

properties :→ (a) It is bright yellow in colour and It has a shine or glow.

(b) It is ductile and malleable.

Ductility :→ It can be beaten into extremely thin sheets of gold leaf.

Malleability :→ capable of being shaped or bent.

(c) It is a good conductor of electricity.

(d) It is soluable (ability to be dissolved).

(e) Hardness :→ A relatively soft metal, gold is usually hardened by alloying with copper, silver or other metals.

(f) It is a dense metal i.e. It has density. [density = $\frac{Mass}{Volume}$].

(g) Its melting point is 1065°C.

(h) It is resistant to corrosion.

uses :→ These are used in current limiters, transport (magnetic-levitation trains), and MRI imaging.

⑤ Iron and steel :→ steel contains iron with a small percentage of carbon added to it. Iron itself is not very 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 of the material.

High Resistivity Materials and their applications :→

① Tungsten :→

Properties :→ (a) It is greyish in colour when in metallic form.

(b) It has a very high melting point (3300°C).

(c) It is a very hard metal and does not become brittle at high temperature.

(d) It can be drawn into very thin wires for making filaments.

(e) Its resistivity is about twice that of aluminium.

(f) In its thinnest form, it has very high tensile strength.

(g) It oxidises very quickly in the presence of oxygen even at a temperature of a few hundred degrees centigrade.

(h) In the atmosphere of an inert gas like nitrogen or argon, or in vacuum, it will reliably work up to 2000°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.

② 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 :→ (a) carbon has very high resistivity (about 4600 micro ohm cm).
(b) It has negative temperature coefficient of resistance.
(c) It is a pressure-sensitive resistance material and has low surface friction.
(d) The current density is 55 to 65 A/cm^2.
(e) This oxidises at about 300°c and is very weak.
(f) It has very good abrasive resistance.
(g) It withstands arcing and maintains its properties at high temperature.

Applications or uses :→
(a) It is used as a brush in electrical machines.
(b) It is used for electrodes in cells and arc lamps, in projectors and in microphones.
(c) carbon arcing tips are used in ckt breaking as they effectively withstand arcs.
(d) As components in electronics and communication equipment.

③ platinum :→
properties :→ (a) It is a grayish-white metal.
(b) It is non-corroding.
(c) It is resistant to most chemicals.
(d) It can be drawn into thin wires and strips.
(e) Its melting point is 1775°c.
(f) Its resistivity is 10.5 micro ohm cm.
(g) It is not oxidised even at high temperature.

Applications or uses :→ (a) It is used as heating element in laboratory ovens and furnaces.
(b) It is used as electrical contact material and as a material for grids in special-purpose vacuum tubes.
(c) platinum-rhodium thermocouple is used for measurement of temperatures up to 1600°c.

④ Mercury :→

properties :→ (a) It is a good conductor of heat and electricity.

(b) It is a heavy silver-white metal.

(c) It is the only metal which is liquid at room temperature.

(d) Its electrical resistivity is 95.8 micro ohm cm.

(e) Oxidation takes place if heated beyond 300°c in contact with air or oxygen.

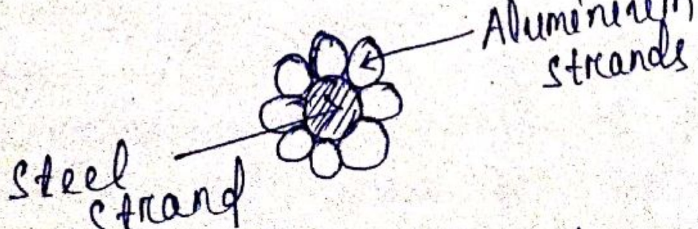
(f) It expands and contracts in regular degrees when temperature changes.

Uses :→ It is used in Mercury vapour lamps, Mercury arc rectifiers, gas filled tubes; for making and breaking contacts; used in valves and tubes.

Stranded Conductors :→ stranded conductors or wire is composed of a no. of small wires bundled or wrapped together to form a larger conductor.

→ stranded wire is more flexible than solid wire of the same total cross-sectional area. stranded wire is used when higher resistance to metal fatigue is required.

→ These conductors are very much popular in electrical power system for transmission and distribution line.



[stranded conductor]

Facts about stranded conductor :→

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

(1) The stranded conductor is having sufficient flexibility, which makes stranded conductor suitable to be coiled easily to transport it over long distance.

(2) For a stranded conductor of same cross-sectional area, the flexibility of conductor increase with the increase of number of strands in conductor.

(3) The stranded conductor is formed by twisting the strands together in layers.

(4) The strands of each layer are laid in helical fashion over the preceding layer. This process is called stranding.

(5) Generally, in successive layer, the stranding is done in opposite direction to preceding layer. This mean, if the strands of one layer are twisted in clockwise direction, the strands of next layer will be twisted in anticlockwise direction and so on 'x' is the no. of layers in conductor.

(6) Generally, the total number of strands in any conductor is given by the formula of,

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

where, 'N' is the total no. of strands in the stranded conductor.

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

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

where, 'D' is the diameter of the conductor, and 'd' is the diameter of each strand.

Bundled conductors :→

→ We call bundled conductor to those conductors which form from two or more stranded conductors, bundled together to get more current carrying capacity.

→ The ampacity i.e. the current carrying capacity of bundled conductors is much increased in comparison to single large conductor owing to reduce the effects.

→ As the bundled conductors have more effective surface area exposed to air, it has better and efficient cooling and hence better performance compared to a single conductor.

→ A bundled conductor also contributes various facilities to the electrical transmission system. A bundled conductor reduces the reactance of the electric transmission line. It also reduces the voltage gradient, radio interference of the transmission lines.

→ A bundled conductor is a conductor made up of two or more sub-conductors and is used as one phase conductor. For voltages greater than 220 KV it is preferable to use more than one conductor per phase which is known as Bundled conductors.

Low Resistivity copper alloys :→

→ Copper alloys also have poor resistance to the inorganic acids. The corrosion resistance of copper alloys comes from the formation of adherent films on the material surface. These films are relatively impervious to corrosion therefore protecting the base metal from further attack.

→ Copper alloys are the metal alloys that have copper as their principal component. They have high resistance against corrosion. The best known traditional types are Bronze, where tin is a significant addition, and brass, using zinc instead. Both of these are imprecise terms, having both been commoney referred to as metals in the past.

Super conductivity :→ Super conductivity is a phenomena in certain metals and ceramics where the resistivity of the material drops to zero below a certain critical temperature i.e. "T_c". These temperatures are low, with most industrial superconductors below 12K [K = Kelvin, the unit of temperature] and higher temperature ceramics just above 130K.

→ Superconductivity, is the complete dissappearance of electrical resistance in various solids when they are cooled below a characteristic temperature. This temperature is called the transition temperature, which varies for different materials but generally is below 20K (−253°C).

→ A superconductor is also a metal that allows electricity to pass through it without resistance at very low temperatures.

→ The best conductors like silver, copper and gold are not superconductors. Superconductivity depends on :-

(a) electron-proton interaction, and
(b) critical temperature (T_c).

<u>Applications or uses</u> :→ Superconductivity can be used for the production of strong magnetic fields. Other applications of superconductivity are based on the effect of an applied magnetic field on the transition between normal and superconducting states.

→ Thus, amplifiers, oscillators, control systems, and especially the logic and information storage functions of a large-scale computer can be provided by the control magnetic field exercises on superconductivity.

→ Magnetic-levitation is an application where the superconductors perform extremely well. Transport vehicles such as trains can be made to float on strong superconducting magnets, virtually eliminating friction between the train and its tracks.

→ SQUIDs [Superconducting Quantum Interference Devices] are used to detect even the weakest magnetic field.

→ These are used in MRI and research magnets. These are also used in power Transmission, cables, Transformers, Motors & generators, Fault current limiters. These can perform a life-saving function is in the field of biomagnetism i.e. in the medical cases Doctors use these superconductors.

Superconductor Materials:→ Superconductor Material classes include chemical elements (e.g. mercury or lead), alloys (such as niobium-titanium, germanium-niobium, and niobium nitride), ceramics, superconducting pnictides or organic superconductors.

→ Superconductors are materials that offer no resistance to electrical current. prominent examples of superconductors include aluminium, niobium, magnesium diboride, and copper oxide etc.

→ Superconductors are the materials which transport the electric charge without resistance and with the display of associated microscopic quantum phenomena such as persistent electrical currents and magnetic flux quantization.

→ There are two types of superconductors. These are:→

(1) Type-1 superconductors → Low temperature superconductors.

(2) Type-2 superconductors → High temperature superconductors.

Applications or uses:→

→ powerful superconducting electromagnets used in maglev trains, magnetic resonance imaging (MRI), and nuclear magnetic resonance (NMR) machines, magnetic confinment fusion reactors (e.g. the beam-stearing and focusing the magnets used in the particle accelerators, low loss power cables.

Future Ideas for the use of superconductors:→

→ The future or futuristic ideas for the use of superconductors, materials that allow electric current to flow without resistance, are myriad; long-distance, low-voltage electric grids with no transmission loss; fast magnetically leviated trains; ultra-high-speed super computers; sufficient motors and the generators; inexhaustible fusion energy and many others, some in the experimental or demonstration stages.

Advantages:→

→ Superconductor technology provides loss-less wires and cables and improves the reliability and efficiency of the power grid.

→ It will also improve the wide-band tele-communication technology, which operates best at high frequencies like giga Hertz unit.

→ It is very useful for improving the efficiency and reliability of cell phones. It is also very useful in aiding the medical diagnosis.

Disadvantages:→

→ Superconductors does not operate at room temperature, Keeping them below the transition temperature involves a lot of expensive cryogenic technology. Thus, superconductors still do not show up in most everyday electronics. So, scientists are working on designing the superconductors that can operate at the room temperature.

Chapter-2

Semiconducting Materials

Definition :→ A semiconductor material is one whose conductivity lies between that of a conductor and an insulator. The two most commonly used semiconductor materials are germanium and silicon.

→ Semiconductor, any of a class of crystalline solids intermediate in electrical conductivity between a conductor and an insulator. 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 reliability, power efficiency and low cost.

Applications of semiconductor Materials :→

→ Semiconductor materials are used in :-

(i) Rectifiers (ii) Temperature-sensitive resistors

(iii) photoconductive and photovoltaic cells.

(iv) varistors

(v) Hall effect generators (vi) strain gauges

(vii) Transistors (viii) LDR and LCD.

Various types of semiconductors commonly used :→

→ The following materials are commonly used as semiconductors are :-

(i) Boron (ii) Carbon (iii) Silicon (iv) Germanium

(v) phosphorus (vi) Arsenic (vii) Antimony

(viii) sulphur (ix) selenium (x) Tellurium and

(xi) Iodine.

Q:→ Why are semiconductors so important?

Ans:→ Semiconductors are especially important as varying conditions like temperature and impurity content can easily change their conductivity. The combination of various semiconductor types together generates devices with special electrical properties, which allow the control of the electrical signals.

→ They are also of high resistance that means higher than the typical resistance materials, but still of much lower resistance than the insulators.

Types of semiconductor Materials:→

→ There are 2 types of semiconductor Materials. There are:- (1) N-type semiconductor and (2) P-type semiconductor.

→ The silicon doped with extra electrons is called an N-type semiconductor. 'N' is for negative, which is the charge of an electron.

→ Silicon doped with the material missing electrons that produce locations that is called holes is called P-type semiconductor. 'P' is for positive, which is the charge of a hole.

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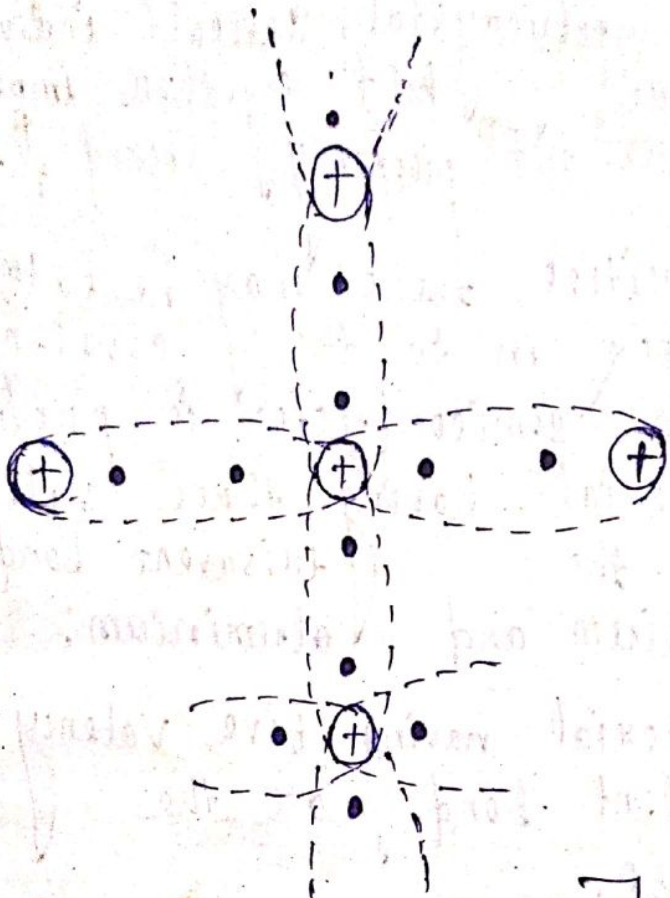
Electron Energy and Energy Band Theory :→

→ When each atom with its neighbouring atom shares electrons in order to fill its valency ring with 8 electrons, a covalent bond is said to be formed.



[Sets of covalent Bonds]

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

→ The above figure shows the covalent bonding. When the atoms enter into this bonding, each atom in effect has 8 valency electrons and this results in making such material in to a good insulator.

→ Covalent bonding leads to the development of a polycrystal. In a polycrystal, several individual crystals are held together imperfectly. The extra atoms are not properly locked in place.

→ Due to the impurities, there may be extra electrons which cannot lock in to the covalent bond structure. Thus, a semiconductor is produced.

→ An impure material having three valency electrons is called the trivalent bond.

Ex :→ gallium, indium and aluminium.

→ An impure material having five valency electrons is called pentavalent bond or the pentavalent group.

Ex :→ antimony, arsenic and phosphorus.

Merits of semiconductor Materials used in Electrical Industry :→ (1) Much smaller in size and light in weight.

(2) When used as rectifiers and transistors, they do not require a heater or filament as is required in electronic tube devices.

(3) consume less power and efficiency is high.

(4) Long life and hardly show ageing effect.

(5) Almost shock-proof.

(6) operate on low voltage.

Excitation of Atoms :→

→ When each electron in an atom is in its normal orbit, the atom is said to be in an unexcited state.

→ To move an electron further away from its nucleus requires additional energy. The additional energy can be obtained from any of the following sources. i.e. light, heat, static electricity, magnetism, kinetic sources.

→ When the electron is in the higher energy level, the atom is said to be in an excited state. The quantum of energy, in electron volts (ev), required to move an electron from one energy level to higher energy level varies from material to material.

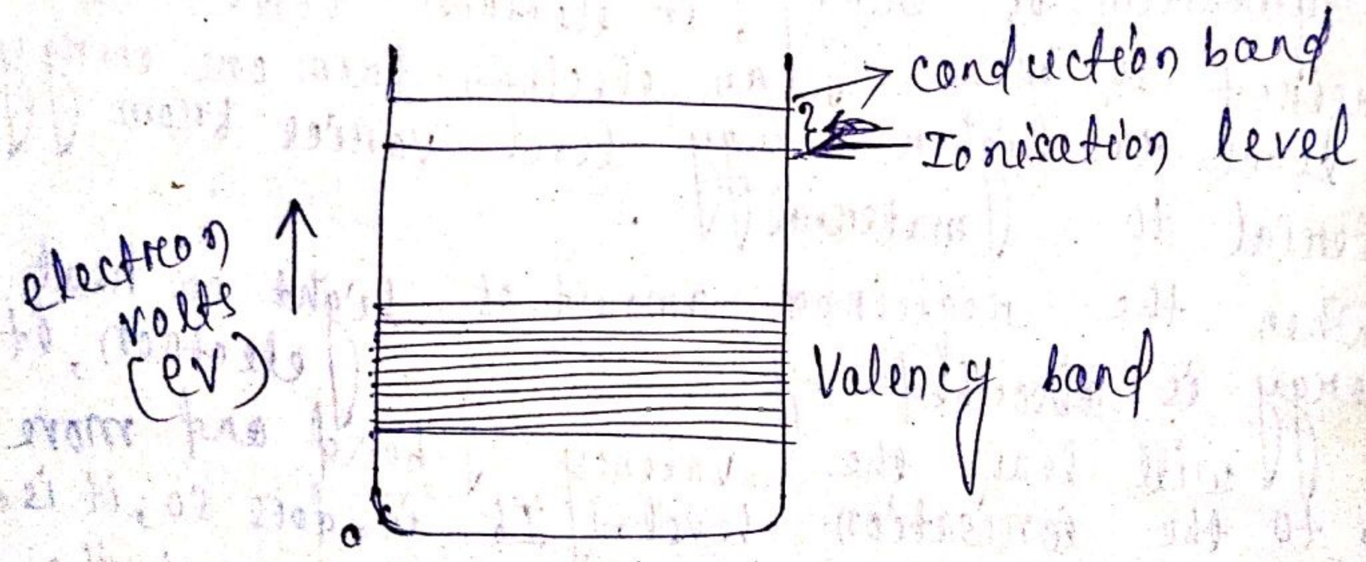
→ When the required amount of light or heat energy is absorbed by a valency electron, it will leave the valency bond and move up to the ionisation level. If it does so, it is released from the attraction forces of the nucleus. Then it is free to float between the atoms and to conduct electricity.

→ An electron above the ionisation level is said to be in the conduction band and is also called a free electron.

→ When the electron leaves the valency band, the resulting atom is no longer neutral but has a positive (+ve) charge and is called positive ion. The atom is said to be ionised.

→ The atom that has been ionised by the loss of an electron, does not remain so for a long time.

→ Its positive (+ve) charge will attract a nearby free electron which will give up its acquired energy. Thus, there is a constant interchange of the electrons being given up and retrieved.



[Energy Band representation of ionisation]

Distinguish Between or Difference between conductors, Insulators and semiconductors :→

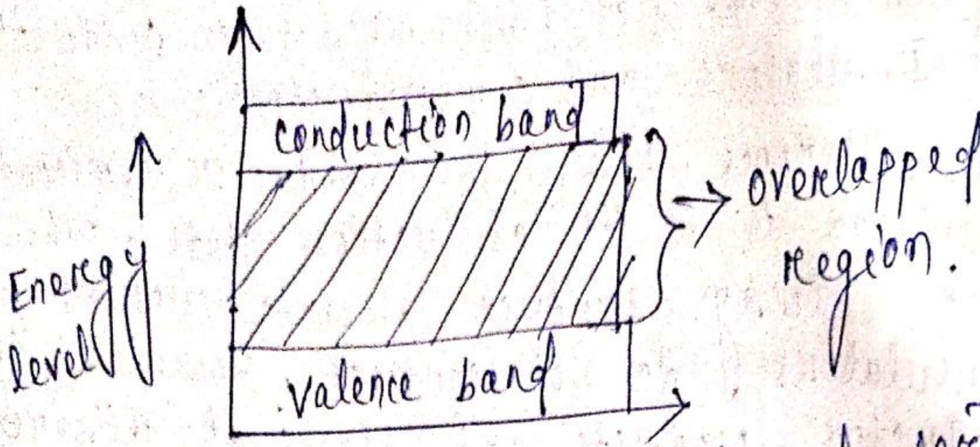
→ The main difference between the conductor, semiconductor and Insulator is in its conduction state. The conductors always conduct electric current while the insulators do not conduct. However, the semiconductor conducts and blocks at different conditions.

Conductor :→ Conductors are the substances that permit or allow easy flow of electric energy through them. We can also say, it permits easy flow of electrons from an atom to the other when a proper electric field is applied to it.

→ These are the materials, that possesses the highest conductivity among the three materials.

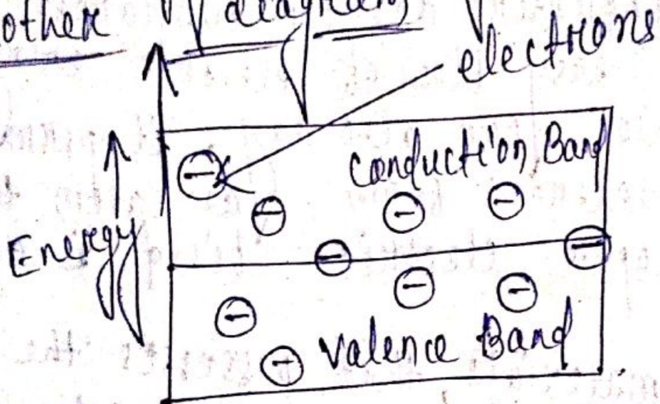
→ Conductivity is the property of a material by which it allows a large amount of current to flow through it. Here The resistivity is low. copper, aluminium, graphite etc. are the good conductor materials. These are used in conducting wires, Transformers, in electrical cords etc.

→ Majorly the movement of electrons inside the material is responsible for its conduction. And these electrons show movement when a certain voltage is applied to it. This voltage applies a force to the electrons due to which it easily starts moving from valence band to conduction band. So, there is no forbidden energy gap exists but it is the overlapped region produced between the conduction band and the valence band.



[Energy level diagram of conductor]

(OR):→ Another diagram



[Energy level diagram of a conductor]

→ In conductive materials, no band gap exist so, electrons move easily using a continuous, partly full conduction band. Conductors are having a (+)ve temperature co-efficient of resistance.

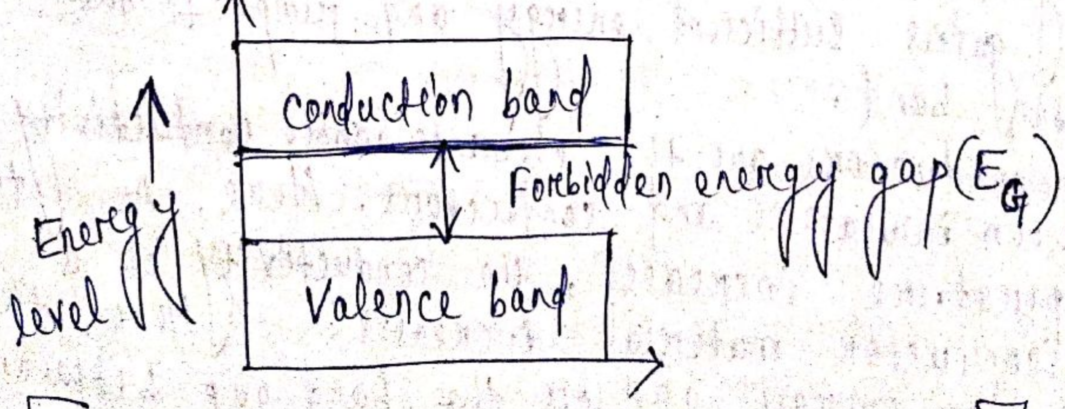
→ As the two bands i.e. valence band and conduction band are overlapped with each other. Thus, when some certain voltage is applied to such materials, then electrons easily moves from valence band to conduction band due to the influence of the electric field. This movement of charge carriers generates a large electric current through the device.

Semiconductor:→ Semiconductors are the materials that possess the property of electrical conductivity less than the conductors. The charge carriers in case of semiconductors are electrons and holes. When the temperature is absolute zero, then no any movement of the charge carriers takes place in case of semiconductors. In such case, it behaves as insulators.

→ But in order to have a considerable flow of the charge carriers to take place certain potential must be provided to them that can excite the electrons to another energy level. Thereby, generating the electric current.

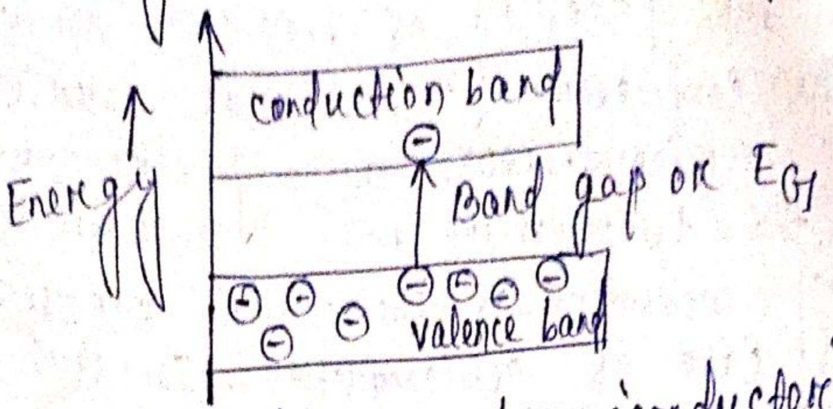
→ Here, the resistivity is moderate and the conductivity is medium. The temperature co-efficient of resistance is negative (-Ve). Here, the forbidden energy gap is small. i.e. 1 eV or 1 electron volt.

→ Silicon, Germanium and arsenic etc. are the examples of semiconductor. These are used in diodes, transistors etc.



[Energy level diagram of semiconductor]

(OR) Another diagram of semiconductor energy level :-



[Energy level diagram of semiconductor]

→ The energy level diagram of semiconductor that shows small band gap between the valence and the conduction band. As we can see in the above figure that, the energy band gap between the valence band and conduction band is present. Though this energy difference was not present in the previously discussed case of conductors.

→ In the case of semiconductors, the two bands do not overlap thus a small energy difference exists between them. So, the electrons in the valence band cannot automatically excite in order to move to the conduction band. But, on applying certain voltage, the electrons in the valence band gains sufficient energy and jumps to the conduction band.

→ Semiconductors are the elements whose conductivity lies between insulators and conductors. Here, As the temperature increases, the conductivity of a semiconductor material increases. Here, the forbidden energy gap or the band gap between the conduction band and the valence band is very small i.e. 1ev.

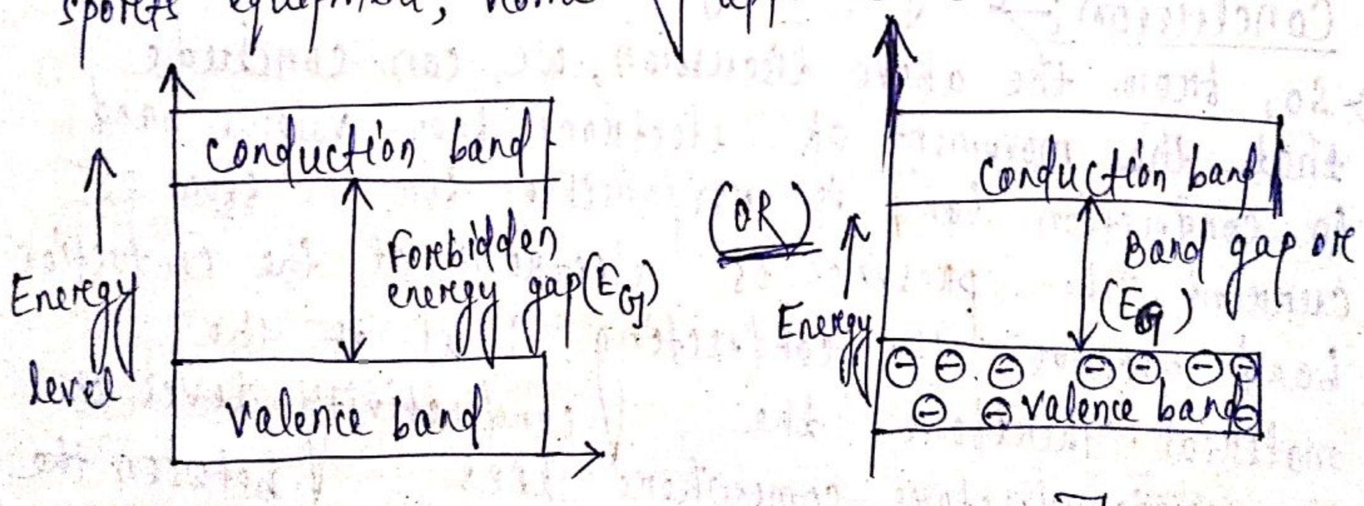
Insulator:→

→ Insulators are the materials that are not good conductors of electric charges. As in case of insulators, current cannot flow easily through them. The energy band gap or the forbidden energy gap(E_G) is so high in case of insulators that even applied potential does not excite the electrons from valence band to the conduction band.

→ But as these possess negative (-ve) temperature co-efficient of resistance hence with the increase in temperature the resistance offered by it decreases.

→ Here the forbidden energy gap is large i.e. greater than 5 electron volt or 5eV. The resistivity is high.

→ Paper, Rubber, glass and plastic etc. are the examples of the insulating material. These are used in sports equipment, home appliances etc.



[Energy level diagram of Insulator]

→ This energy level diagram of insulator showing large band gap between the valence band and the conduction band. The valence band remains full since no movement of electrons occurs and as a result, the conduction band remains empty as well.

→ Here, as we can see that large band gap exist between the valence band and the conduction band. This large band gap does not allow the electrons to jump into the conduction band. Hence, the current flow is not possible.

→ The band gap or the forbidden energy gap (E_g) in case of the insulator is larger as compared to both the conductors and the insulators.

→ However, there exists a breakdown case of insulating materials, in which, when an extremely high temperature is provided or supplied then it causes the electrons to overcome the large energy difference thereby moving to the conduction band.

<u>Conclusion:</u>→

→ So, from the above discussion, we can conclude that the movement of electrons from valence band to conduction band is responsible for the flow of current. The presence of electrons at the conduction band decides the conducting level of the material. Therefore, the conductivity level of the semiconductor somewhere lies between the conductors and the insulators.

Covalent Bonds :→

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

→ Covalent bonds are also the chemical bonds between two non-metal atoms. An example is water, where hydrogen(H) and oxygen (O) bond together to make (H_2O). As they are both non-metals which need to gain electrons - they have to share, so their outer shells cross over in order to have a full outer shell.

→ A compound which formed from the sharing of electrons between two or more non-metal atoms is known as a covalent compound.

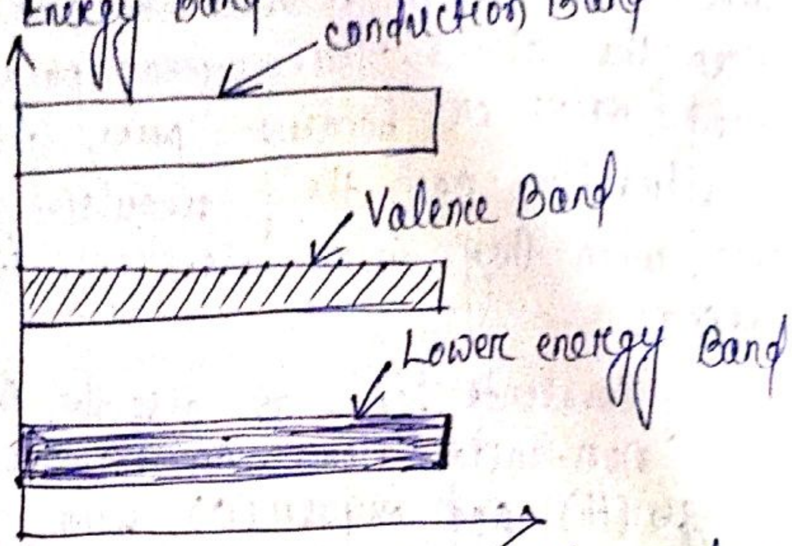
Intrinsic and Extrinsic semiconductors :→

Intrinsic semiconductors :→ The pure type of semiconductor is the intrinsic type semiconductors. The conductivity of the intrinsic semiconductor becomes zero at room temperature.

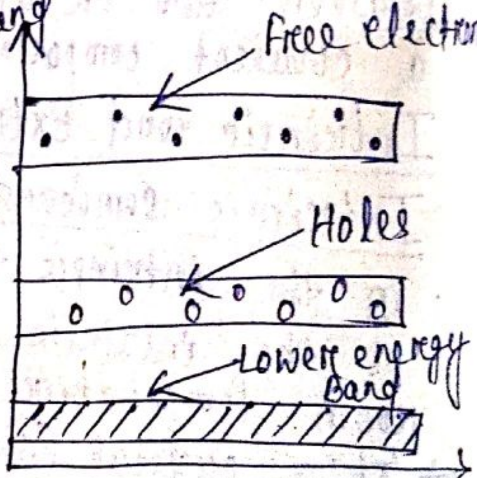
→ If a crystal (silicon or germanium) does not contain any impure atoms (contains only one type of atoms), it is called an intrinsic material. When an electron is freed from the atom of an intrinsic material, it breaks a covalent bond and leaves behind a vacancy (called a hole).

→ The free electron and the hole form an electron-hole pair. The higher the temperature, the greater the number of free electrons and holes. When a voltage is applied to an intrinsic material, it acts as a conductor.

→ On the basis of the energy band phenomenon, an intrinsic semiconductor at absolute zero temperature is shown below :-



→ Its valence band is completely filled and the conduction band is completely empty. When the temperature is raised and some heat energy is supplied to it, some of the valence electrons are lifted to conduction band leaving behind the holes in the valence band as shown below :-



→ The electrons reaching at the conduction band move randomly. The holes created in the crystal also free to move anywhere. This behaviour of the semiconductor shows that they have a negative (-Ve) temperature co-efficient of resistance. This means that with the increase in temperature, the resistivity of the material decreases and the conductivity increases.

Extrinsic Semiconductors :→

→ Pure silicon or germanium exhibits the characteristics closer to that of an insulator than a semiconductor. In order to make a material conducting, a small quantity of impurity must be added to it. The addition of impurity makes pure germanium or silicon a conductor. The process of adding impurities is called "doping". A material which has been doped is called an extrinsic material.

→ The extent to which the impurity has been added is called the "doping level". When a pentavalent group provides an extra electron to the semiconductor material, the atom of the material which donates the extra electron is called a "donor atom".

→ When a trivalent group is added to intrinsic materials such as silicon, one covalent bond is broken, that is, a hole is created. An electron from an adjacent atom can fill the hole which is now moved to another atom.

→ The doping atom has now one surplus negative (-ve) charge and has become a negative ion. A hole is the absence of an electron and hence has a positive charge. The doping element is an "acceptor", since it takes or accepts an electron.

→ A semiconductor to which an impurity at controlled rate is added to make it conductive is known as an extrinsic semiconductor.

→ An intrinsic semiconductor is capable to conduct a little current even at room temperature, but the extrinsic semiconductor is not useful for the preparation of various electronic devices. Thus, to make it conductive a small amount of suitable impurity is added to the material.

Doping: → The process by which an impurity is added to a semiconductor is known as doping. The amount and type of impurity which is to be added to a material has to be closely controlled during the preparation of extrinsic semiconductor. Generally, one impurity atom is added to a 10^8 atoms of a semiconductor.

→ The purpose of adding impurity in the semiconductor crystal is to increase the no. of free electrons or holes to make it conductive. If a pentavalent impurity, having five valence electrons is added to a pure semiconductor a large no. of free electrons will exist.

→ If a trivalent impurity having three valence electrons is added, a large no. of holes will exist in the semiconductor.

→ Depending upon the type of impurity added the extrinsic semiconductor may be classified as (N) n-type semiconductor and P-type semiconductor.

N-type semiconductor :→

→ When a small amount of pentavalent impurity is added to a pure semiconductor providing a large number of free electrons in it, the extrinsic semiconductor thus formed is known as n-type semiconductor.

→ The conduction in the n-type semiconductor is because of the free electrons denoted by the pentavalent impurity atoms. These electrons are the excess free electrons with regards to the number of free electrons required to fill the covalent bonds in the semiconductors.

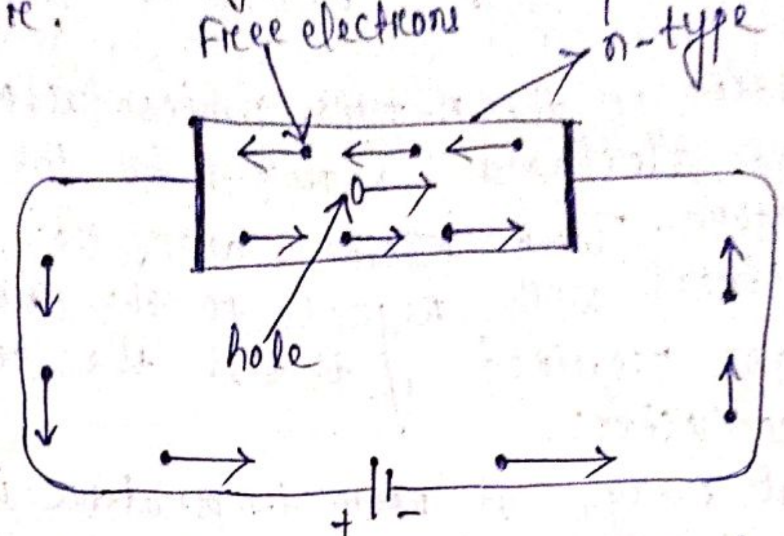
→ When thermal energy at room temperature is imparted to the semiconductor, a hole-electron pair is generated and as a result, a minute quantity of free electrons are available. These electrons leave behind the holes in the valence band.

→ Here, 'n' stands for negative material as the number of free electrons provided by the pentavalent impurity is greater than the number of holes.

→ When a pentavalent impurity is added to an intrinsic material such as silicon or germanium, only four of its valency electrons lock into the covalent bond formation of atomic structure. The fifth valency electron of the impurity atom is free to wander through the crystal.

Conduction through n-type semiconductor :→

→ In the n-type semiconductor, a large no. of free electrons are available in the conduction band which are donated by the impurity atoms. The figure below shows the conduction process of an n-type semiconductor.



→ When a potential difference is applied across this type of semiconductor, the free electrons are directed towards the +ve terminals. It carries an electric current. As the flow of current through the crystal is constituted by free electrons which are carriers of −ve charge, therefore, this type of conductivity is known as negative or n-type conductivity.

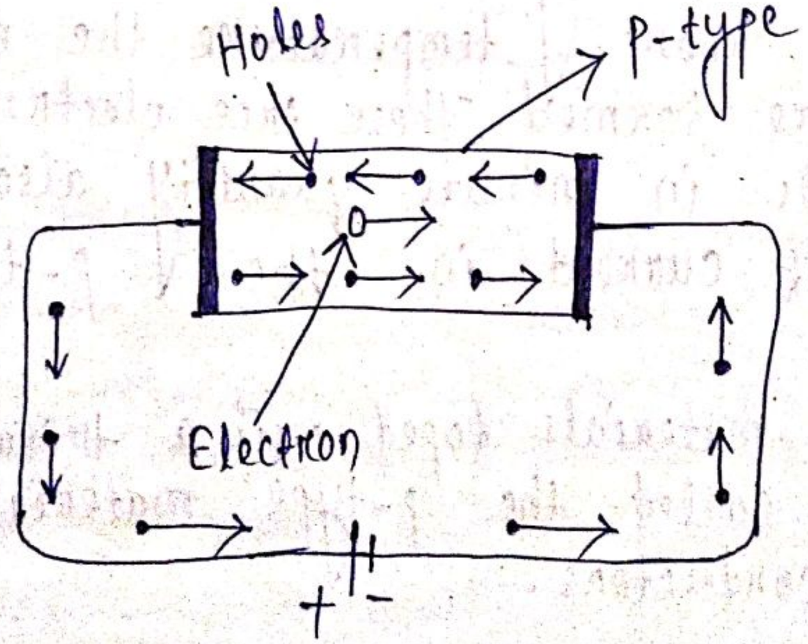
→ The electron-hole pairs are formed at room temperature. These holes which are available in small quantity in valence band also consists of a small amount of current. For practical purposes, this current is neglected.

P-type Semiconductor :→

→ The extrinsic p-type semiconductor is formed when a trivalent impurity is added to a pure semiconductor in a small amount, and as a result, a large no. of holes are created in it. A large number of holes are provided in the semiconductor material by the addition of trivalent impurities like Gallium and Indium. Such type of impurities which produces p-type semiconductor are known as an Acceptor impurities because each atom of them create one hole which can accept one electron.

Conduction through P-type semiconductor :→

→ In P-type semiconductor large number of holes are created by the trivalent impurity. When a potential difference is applied across this type of semiconductor as shown in the figure below.



→ The holes are available in the valence band are directed towards the negative terminal. As the current flow through the crystal is by holes, which are the carrier of positive (+ve) charge, therefore, this type of conductivity is known as positive or p-type conductivity. In a p-type conductivity or p-type semiconductor the valence electrons move from one covalent to another covalent bond.

→ The conductivity of n-type semiconductor is nearly double to that of p-type semiconductor. The electrons available in the conduction band of the n-type semiconductor are much more movable than the holes available in the valence band in a p-type semiconductor. The mobility of the holes is poor as they are bound to the nucleus.

→ Even at the room temperature the electron hole pairs are formed. These free electrons which are available in minute quantity also carry a little amount of current in the p-type semiconductors.

→ The intrinsic materials doped with a trivalent impurity are called the p-type materials or p-type semiconductors.

Minority and Majority Carriers :→

→ In N-type material, conduction takes place through the electrons created mostly by the doping and a small number created by thermal generation.

→ The small number of holes created by thermal generation move in opposite direction. In N-type material, the no. of free electrons is large. These electrons are called majority carriers. Holes are in small numbers and are called minority carriers.

→ In P-type material, the holes are majority carriers and the electrons are the minority carriers.

Distinction between Intrinsic and Extrinsic Semiconductors :→

Intrinsic semiconductor	Extrinsic semiconductor.
(1) These materials do not contain any impurities.	(1) These contain added impurities.
(2) Conduction takes place by thermally or optically excited electrons.	(2) Conduction takes place by the free electrons or holes.
(3) Conductivity takes place at higher temperature.	(3) Conductivity takes place at normal temperature.
(4) Conductivity increases with the increase of temperature.	(4) Conductivity does not depend on temperature. It depends on the level of doping.

Defination of Fermi level in semiconductors :→

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

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

→ The fermi level is the energy level which is occupied by the electron orbital at the temperature equals 0°K [K=Kelvin, the other unit of temperature]. The level of occupancy determines the conductivity of different materials.

→ The fermi level is the chemical potential of a system of electrons in a solid, which depends on the temperature.

Applications of semiconductor Materials :→

→ Semiconductor materials are used in :-

(i) Temperature sensitive resistors or Thermistors.
(ii) photoconductive and photovoltaic cells
(iii) Varistors
(iv) Transistors
(v) Hall effect generators
(vi) strain gauges.
(vii) LDR and LCD
(viii) Rectifiers.

Temperature sensitive elements (Thermistors) :→

→ If the temperature of a semiconductor material is increased, that causes a decrease in its resistance. This property is used in the temperature - sensitive elements which are called as 'thermistors'.

→ The thermistors are thermally sensitive material (resistors). They are made from oxides of certain metals such as copper, manganese, cobalt, iron and zinc.

Applications of Thermistors :→

→ Thermistors find applications in temperature measurements and control. They sense temperature variations and convert these variations into an electrical signal which is then used to control the heating devices. Thermistors are also used for the measurement of radio frequency power, voltage regulation and time delay circuits.

photoconductive cells:→

→ The resistance of the semiconductor materials is low under light and increases in darkness. photoconductive cells can be used in the applications which require the control of a certain function or event according to the colour or intensity of light.

Applications:→ They are used in burglar alarms, flame detectors and control for street lights.

photovoltaic cells:→

→ photovoltaic cells are the devices that develop an emf when illuminated. They convert the light energy directly in to electrical energy.

Applications:→ The applications of the photovoltaic cells are in the photographic exposure meters, lighting control systems, automatic aperture control in the camera.

Varistors:→ The resistance of semiconductors varies with the applied voltage. This property is used in devices called varistors.

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

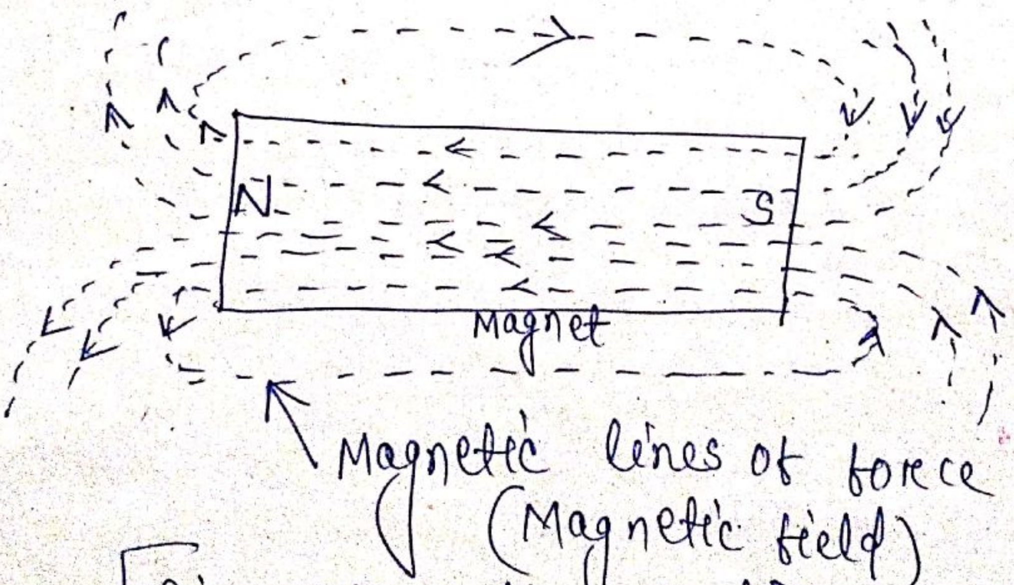
Magnetic ckts or Magnetic Materials

Introduction :→

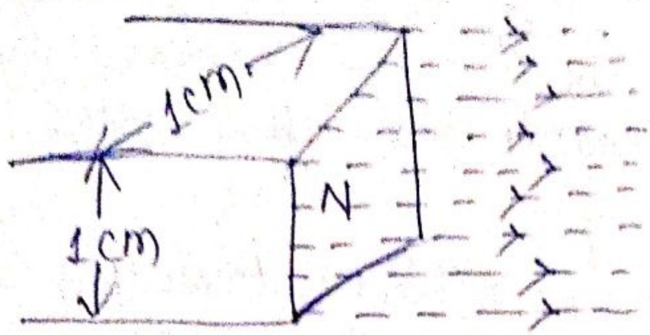
→ Materials which can be magnetised are called the magnetic materials.

→ A magnetic circuit is made up of one or more closed loop paths containing a magnetic flux. The flux is usually generated by permanent magnets or the electromagnets and confined to the path by magnetic cores consisting of ferromagnetic materials like iron, although there may be air gaps or other materials in the path.

→ The area or the region around the material where the magnetic properties can be detected is known as magnetic field.



[Fig-a → Magnetic field]



(fig-b → Magnetic lines of force)

Flux density $= B = \frac{\phi}{a} = \frac{\text{magnetic lines of force}}{\text{area of the pole-face}} = Wb/cm^2$

→ Magnetic field strength is the force the field could exert on any unit magnetic pole placed in the field. This is also known as magnetic force or magnetic in density.

→ Unit pole is that pole which when placed at a distance of 1 cm in air or vacuum from a like pole exerts a force of 1 dyne.

→ Flux or magnetic lines of force are the imaginary lines or path of field in a given direction. The lines of force are supposed to make a closed path starting from 'N' pole and ending at 'S' pole without any loss. These lines of force are measured in weber (Wb).

1 Wb = 10^8 lines.

symbol of flux is ϕ (phi).

Magnetic ckt :→ It is the path of the magnetic lines of force or flux forming a closed circuit.

Magnetic force :→ It is the force exerted by a magnet on another magnet to either attract or repel it.

→ It is also known as the magnetizing force (H).

→ The force exerted by a magnet which is determined by the sum of all lines of the magnetic flux present in a magnetic field.

Intensity :→ In physics, intensity of radiant energy is the power transferred per unit area, where the area is measured on the plane perpendicular to the direction of propagation of the energy.

→ In the SI system, it has the units of watts per square meter.

→ It is also the magnitude of a quantity (such as force or energy) per unit (as of area, charge, mass or time).

→ It is also the quality or state of being intense, especially the extreme degree of the force, strength, and energy etc.

Magnetomotive Force (mmf) :→ It is the force which drives the flux through a magnetic circuit.

→ It is also written as MMF.

→ In physics, the magnetomotive force (mmf) is a quantity appearing in the equation for the magnetic flux in a magnetic circuit, often called ohm's law for the magnetic ckts. It is the property of certain substances or the phenomena that give rise to magnetic fields.

$$\boxed{F = \phi R}$$

Where, ϕ = magnetic flux
and R = Reluctance of the ckt.

Reluctance:→ It is the opposition offered by the material to the flux.

permeability:→ It is the property of a material by virtue of which it allows itself to be magnetized. Permeability value varies from material to material depending upon the saturation and the temperature.

→ A good magnetic material should have high permeability. It is denoted by the symbol 'μ'.

$$\boxed{\text{permeability} = \mu = \frac{B}{H}}$$

Where μ (mu) = permeability
B = flux density
H = magnetising force

Flux density (B):→ It is the flux per unit area. and it is represented by the symbol 'B'.

$$\boxed{\text{Flux density} = B = \frac{\phi}{a}}$$

Where, ϕ = flux or magnetic flux
a = area or unit area.

Residual Magnetism or Remanance :→

→ It is the magnetic flux density which still remains in the magnetic materials even when the magnetising force is completely removed.

→ Remanance or remanent magnetization or residual magnetism is the magnetization left behind in a ferromagnetic material (such as iron) after an external magnetic field is removed. When a magnet is magnetized it has remanance.

Permeance :→ It is the property of allowing the passage of lines of magnetic flux.

→ In a magnetic ckt, permeance is a measure of the quantity of magnetic flux for a number of current turns. A magnetic ckt almost acts as though the flux is conducted, therefore permeance is larger for large cross-sections of a material and smaller for smaller cross-section lengths.

Coercive Force :→ It is the demagnetizing force which is necessary to neutralise completely the magnetism in the magnetic materials.

Retentivity :→ It is the power of retaining magnetism in the magnetic materials even after the magnetizing force is removed.

→ Retentivity is the ability of a substance to retain or resist magnetization, frequently measured as the strength of the magnetic field that remains in a sample after removal of an inducing field.

→ Magnetic retentivity is a measure of the residual flux density corresponding to the saturation induction of a magnetic materials.

→ Materials of permanent magnet : has the high retentivity and high coercivity.

Classification of Magnetic Materials :→

→ Magnetic materials are classified according to their relative permeability. These are :→

(1) Ferromagnetic Materials.

(2) Paramagnetic Materials

and (3) Diamagnetic Materials.

(1) Ferromagnetic Materials :→ These are the materials (in which relative permeability is greater than unity (unity means 1)) and dependent on the field strength. These materials are strongly magnetized in the direction of the field. These are strongly attracted to a magnet.

→ These materials will retain their magnetization for some time even after the external magnetizing field is removed. This property is also called hysteresis. Among all the types of magnetic materials it is the strongest type.

Examples :→ Iron, cobalt and nickel.

(2) Paramagnetic Materials :→ These are the materials in which the relative permeability is slightly greater than unity and they are slightly magnetised, or weakly magnetised in the direction of the magnetizing field when placed in a magnetic field. In the non-uniform external magnetic field, paramagnetic substances move from weak field region to a strong field region.

→ Magnetization of the paramagnetic substances is inversely proportional to the absolute temperature.

Example :→ Aluminium, platinum and oxygen.

(3) Diamagnetic Materials :→ These are the materials in which the relative permeability is slightly less than unity or 1.

→ Diamagnetic materials are those materials that are freely magnetized when placed in the magnetic field. We can relate to these materials in our daily lives if we think of the substances that are non-magnetic. These include substances such as wood, water, some plastics and few metals as well. These are the materials which are usually repelled by a magnetic field. The substances are weakly repelled by the field, so in a non-uniform field, these substances have a tendency to move from a strong to a weak part of the external magnetic field.

Examples :→ silver, copper, bismuth and hydrogen.

Relative permeability :→ The relative permeability of the material is the comparision of the permeability concerning the air or vacuum. The actual permeability of the air or vacuum is very poor as compared to the absolute permeability.

→ The relative permeability of the material is the ratio of the permeability of any medium to the permeability of air or vacuum. It is expressed as,

$$\mu_r = \frac{\mu}{\mu_0}$$

$$\Rightarrow \mu = \mu_0 \mu_r$$

→ The relative permeability (μ_r) of the air and the non-magnetic material is '1'. [i.e. $\frac{\mu_0}{\mu_0} = 1$].

Curie point:→ Curie point is the temperature at which the ferromagnetic materials lose their magnetic property. This temperature is a characteristic of the magnetic materials and differs from material to material. At its curie temperature, iron ceases to be ferromagnetic and becomes paramagnetic.

→ Above the curie temperature, the domain structure tends to disrupt ; domains lose their alignment and become arranged in a random fashion. Thus the material loses its ferromagnetic property.

→ Curie point is also called as curie temperature, the temperature at which certain magnetic materials undergo a sharp change in their magnetic properties. In the case of the rocks and minerals, remanent magnetism or residual magnetism appears below the curie point about 570°c (1060°F) for the common magnetic mineral magnetite.

Magnetostriction:→ It has been established that when the ferromagnetic materials are magnetised, a small change in dimensions of the materials takes place. There is a small extension with corresponding reduction of cross-section of the crystals 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 the transformers and the chokes.

→ Magnetostriction is a property of the magnetic materials that causes them to change their shape or dimensions during the process of magnetization. The variation of materials magnetization due to the applied magnetic field changes the magnetostrictive strain until reaching its saturation value.

→ Magnetostriction can be measured by direct and indirect methods. For the crystalline materials, the use of strain gauges is most common. Strain gauges are easy to handle but limited in sensitivity. The most sensitive method is the capacitance method, but it requires a special sample preparation.

→ Magnetostrictive materials are used to convert electromagnetic energy into mechanical energy and vice versa. This effect can be used to create sensors that measure a magnetic field or detect a force. The magnetic field or force applied would create a strain in the material, which can be measured.

—— X ——