1

Chapter

CONDUCTINGMATERIALS

1.1 Introduction

Itisthosesubstancesinwhichelectriccurrentpassthrougheasily.Example:Silver,iron,cu, gold,Al,humanbody,earth,salt.Intermsofenergyband thevalenceandconductionbands overlap each other due to this overlapping; a slight potential difference.

ClassificationofElectricalMaterials

Materialsusedinthe electrical engineering field areclassified basing ontheir propertiesand applications.

- ConductorMaterials
- SemiconductorMaterials
- InsulatingMaterials
- Dielectricmaterial
- MagneticMaterials
- MaterialforSpecialpurpose

1.1.2ClassificationofMaterialsBasedonAtomicStructure

The materials such as gold, silver, copper and aluminum which can neither be broken into other substancesnorbecreatedare called“elements‟.Thesmallestparticles intowhich anelementcan be dividedhaving the identity of theelementarecalled“atoms”.Theseparticlescannotbe divided further. The atom although extremely small, has a complexinternalstructure of itsown. This resembles theminiaturesolarsystem.An atom consistsof the central core callednucleus, with electrons revolving around it as well as spinning around themselves. The nucleus contains protons and neutrons. Each proton possesses as much positive charge as an electron possesses negative charge (1.6×10^{-19}C).

Conductor Materials the number of protons inside the nucleus is equal to the number of electrons revolving around it. This number is called atomic number of the element. The neutron does not possessanycharge. Therefore, the atomiselectrically neutral. Themassof a protonor aneutron is1.672×10^{-27}kg.Which is 1850timesmorethanthatof anelectron?Themassofanelectron is 9.107×10^{-31}kg. The electron’sdiameteristhreetimesthat of a proton.The weightof protons andneutronstogetheriscalledatomicweightoftheelement.Theelectronsareheldintheatom by attractive force between protons and electrons which carry opposite charges. Theelectrons revolve insuccessiveorbits orshells.Theorbitsshouldbevisualizedtobein differentplanes andnotas they appearto be in thefigure.Thenumberof electronsthateachshellcan accommodateisgivenby**$2n^2$**wherenisthenumberof theshellscountingfromtheinnermost shell.Theinnermostshell(i.e.thefirstshell)canaccommodate2electrons,thesecondshell8, the third 18andso on.The outermostshell innocasewill containmorethan 8electronsin the first shell, 8 in the second, 8 in the third and 1 in the fourth even though the third shell can accommodate 18 electrons according to theformula.Within theshell therearesub-shells which are classifiedas:s,p,d,f,g,s andpandsoon.There are energy levels again in thissub–shells. Thesub-shellshasoneenergylevel,phasthreelevels,dhasfivelevelsandsoon.Notmore than two electrons occupy thesameenergy level, onespinninginone directionandtheotherin the opposite direction. Thus the sub-shell

Scanaccommodate$1\times2=2$electrons

Pcanaccommodate$3\times2=6$electrons

Dcanaccommodate5××2=10electrons

Fcanaccommodate7×2=14electrons

Gcanaccommodate9×2=18electronsandsoon.

AccordingtoPauliExclusionPrinciple,thestateofanyelectronisdefinedbyfourQuantum numbers:

- Theshellnumber1,2,3,etc.ofK,L,M,N,etc.
- Thesub-shellnumbers,p,d,f,getc.
- Theorbitnumberinsub-shell1s,2s,3s,etc.,and
- TheelectronspinsQuantumnumber+1/2and-1/2

The electrons nearerto nucleus aremore firmly held than thosefartherfromit.Theenergy requiredtopulloutoneelectronfromthefirstorbitismorethantheenergyrequiredtopullout one electron from thesecondorbit andso on. Thatis, electronspossessadefiniteamountof energy, called quantum, depending upon the orbit.

Hence, orbitsare referred to as energy levels. The valence of an element isdetermined by the numberofelectronsitcanreceiveorgiveawayfromitsoutermostsub-shelltoanotherelement in a reaction.The elements having 3 or less valence electrons give awaytheseelectronsbut elements having 5 or more valence electrons; do receive such electrons to make the total as 8, for stability.Thevalenceelectrons are very looselyheld andcontribute tothepropertiesofthe element.If thevalenceorbit contains 8 electrons,then theatom is completeandstable;ifit contains less than 8, the atom is unstable andvery easily givesout or receivesvalence electrons fromthe neighbor to complete its valence orbit.

1.2 Resistivity

Resistivity orspecific resistance of amaterial may be defined as: "Resistanceoffered between the opposite faces of a meter cube of that material."

Theunitofresistivityisohmmeter(Ω-m).

Resistance

It is asubstance which opposestheflowof currentis known as Resistance SIunitofresistanceis ohm.

ResistanceofaconductordependsonitsLength(L),AreaofCross-section(A)ofthematerialas showninfigure1.1andisgivenbyaccordingtoLawofResistance.

Accordingtolawofresistance.

- Theresistanceofamaterialisdirectlyproportionaltolengthoftheconductor.
- The resistance of amaterial is inversely proportional to area of cross-section of the conductor.

$R \alpha L$

$R \alpha 1/A$

So, $R \alpha L/A$

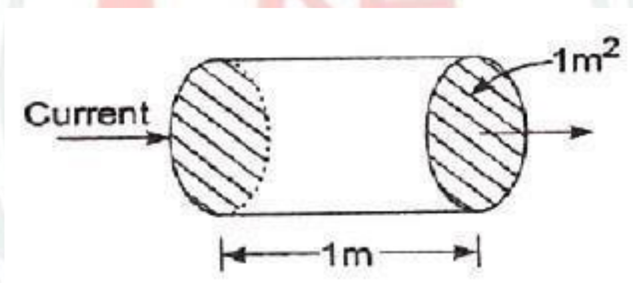

Figure1.1ResistanceofaconductordependsonitsLength(L),AreaofCross-section(A) ofthematerial.

Or $R=\rho L/A$ (whereρisknownasresistivityofmaterial)

Therefore

$\rho = AR/L$

WhenR= Resistance in Ohms (Ω) L=

Length in m

A=Areaof crosssectioninm^2

ρ=resistivityorSpecificresistanceinΩ-m

ρ = A R / L = m^2ohm/m = ohm –m IfA=1 m^2 L= 1m

R = ρ

WhereR = Resistance in Ohms (Ω) L

= Length in m,

A=Areaofcrosssectioninm^2

ρ=resistivityinΩ-m

TemperatureCoefficientofResistance

Basedontemperatureeffect,electricalmaterialscanbeclassifiedintotwogroups:

- **Positivetemperaturecoefficient** meansthattheresistanceof someofthemetalsand alloys increases when their temperature is raised.ie (T α R).
- **Negative temperature coefficient**meansthattheresistanceof someofthematerials, i.e.,carbonandinsulatorsandelectrolytes,decreaseswhentheirtemperatureisraised.ie (Tα1/R).

1.4 PropertiesofConductors

A. ElectricalProperties

- Theconductivitymustbegood.
- Electrical energy displayed in the form of heatmust be low.
- Resistivity must be low.
- Temperatureresistanceratiomustbelow.

B. MechanicalProperties

- Ductility:It hasthatpropertyofamaterialwhichallowsittobedrawnintoa wire.
- Solderability:Thejointshouldhaveminimumcontactresistance.
- Resistancetocorrosion:Shouldnotgetrustedwhenusedinoutdoors.
- Withstandstressandstrain.
- Easytofabricate.

C. EconomicalFactors

- LowCost
- EasilyAvailable

1.5 CharacteristicsofaGoodConductorMaterial

Theconductor materialsshouldhavelowresistivitysothatthedesiredofaconductormaterial depends on the following factors:

- Resistivity of the materials.
- Temperaturecoefficientof resistance
- Resistance againstcorrosion
- Oxidationcharacteristics
- Ease of soldering and welding
- Ductility
- MechanicalStrength
- Flexibilityand abundance
- Durability andlow cost

1.6 LowResistivityMaterial

Low resistivity material possessing very low value of resistivity. These are usedforsuch applications where power loss and voltage drop should be low, these are used in house wiring as conductorforsupplying powertovariousconductors andthesearealsousedinelectrical machines as windings to carry electric current.

- Lowtemperatureco-efficient
- Highmechanicalstrength
- Longservicelife
- Low cost and easily available in market

Example: Copper, Silver, Gold,Aluminum, Steel,etc.

Low Resistivity Materialsand theirApplications

Copper

Properties:

- Pure copperis oneof thebest conductors of electricity and its conductivity ishighly sensitive to impurities.
- Itisreddish-brownincolour.
- Itismalleableandductile.
- Itcanbeweldedatredheat.
- Itishighlyresistanttocorrosion.
- Meltingpointis1084^{o}C.
- Specificgravityof copperis8.9.
- Electricalresistivityis1.682microohm/cm.
- Itstensilestrengthvariesfrom3to4.7tones/cm^{2}
- Itformsimportantalloyslikebronzeandgun-metal.

Applications: Wires, cables, windings ofgeneratorsandtransformers,overheadconductors,busbar etc. because it is such a good conductor of electricity, copper is mostly used in electrical generatorsandmotors,forelectricalwiring,and in electronic goods,such as radio andTV sets. Copper also conducts heat well, so it is used in motor vehicle radiators, air-conditioners and homeheatingsystems.Theaveragehomecontains 400poundsofcopperthatisusedfor electrical wiring, pipes and appliances.

Figure1.2Copperwires

Hard drawn (cold-drawn) copper. Conductor it is mechanically strong with tensile strength of 40 Kg/mm^2.

It is obtained by drawing cold copper bars into conductor length. It is used for overhead line conductors and bus bars.

Copperis so importantisthat it can bemade into alloys. Thatmeansit can be combined with othermetals to make new copper alloys, like brassandbronze.These areharder, strongerand more corrosion resistant than pure copper.

Annealed Copper(SoftCopper)Conductor. Itis mechanically weak, tensile strength20Kg/mm^2, it is easily shaped into any form.

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

Silver

Itisbestknownelectricalconductor.

Properties:

- Itisverycostly.
- Itisnotaffectedbyweatherchanges.

- Itishighlyductileandmalleable.
- Itsresistivityis165microohmcm.
- Asoft,white,lustrous.
- Itexhibitsthehighestelectricalconductivity

Applications:

Used in specialcontact,highrupturingcapacityfuses, radiofrequencyconductingbodies, leads invalves andinstruments.Silveris usedinmakingofsolder,jewellery;Silverchlorideisusedas glasses.

Figure1.3Left:Tinsolderingsilverwires;Right:Silvercontactwires

1.6.3Aluminum

Properties:

- Pure aluminum hassilvery colour and lustre.It
- offers high resistance to corrosion.
- Itisductileandmalleable.
- Itselectricalresistivityis2.669 microohms/cmat20°C.It is
- good conductor of heat and electricity.
- Its specific gravity is
- 2.7.Its melting point
- is658°C.
- Itcannotbesolderedorweldedeasily.
- Itischeaperthancopper.
- Itislighterin weight.
- Itissecondinconductivity.

- Athighervoltages,itcauses lowercoronalloss.
- Asthemeltingpointoftheconductorislow,theshort-circuitcurrentwilldamageit.
- Weldingofaluminumismuchmoredifficultthanthatofanyothermaterial

Figure1.4ACSRconductors

Applications:

Overhead transmission line conductor, busbars, and ACSR conductors. Wellsuitedforcold climate.Aluminum is used foraircraft, trains,overhead power cables,saucepansand cooking foil.

Aluminum Conductorwith SteelReinforcement(ACSR).Analuminumconductorhavinga central force of galvanized steel wires is used for high-voltagetransmissionpurposes.Reinforcementisdonetoincreasethetensilestrengthof aluminumconductor.TheACSR

Therearefourmajortypesofoverheadconductorsusedforelectricaltransmissionand distribution.

- AAC-AllAluminumConductors.
- AAAC-AllAluminumAlloyConductors.
- ACSR-AluminumConductorSteelReinforced.
- ACAR-AluminumConductorAluminum-AlloyReinforced.

1.6.4Steel

Steelcontains iron with asmallpercentageof carbon addedtoit.Iron itself isnotstrongbut when carbon is added to it, it assumes very goodmechanical properties. Thetensilestrengthofsteelishigherthanthatofiron.Theresistivityofsteelis8-9timeshigherthanthatofcopper.Hence,steelisnotgenerallyusedasconductormaterial.Galvanizedsteelwiresareused as overheadtelephonewiresandasearthwires.Aluminum increase conductors aresteel-reinforcedto their tensile strength.

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Applications:

Steelisusedinoverheadtelephonewire.

TypeofSteel	IronAlloyedWith	TypicalUse
lowcarbonsteel	about0.25percentcarbon	carbodypanels
highcarbonsteel	upto2.5percentcarbon	cuttingtools
stainlesssteel	chromiumandnickel	cutleryandsinks

1.6.5Gold

- Gold isa good conductorof heat and electricity Its
- melting point is 1,064°C
- Itis abright,slightlyreddishyellow,dense,soft,malleable,andductilemetal

Applications:

It is also used in electronicscircuitmanufacturing,goldpowderandgoldsheet is usedfor soldering a semiconductor, it is used for making a ring.

1.7 BundledConductors&UndergroundCables

A bundle conductor is a conductor made up of two or more sub-conductors; bundled conductor is exclusively usedin EHVAC line.Itis usedformorethan220kv,whichhelpstoreducethe corona effect.

The effective diameter of bundled conductor is high, The bundled conductor consists of a two or more parallel conductor sub conductor at a spacing of several diameter these group of conductor formsaphaseconductor,thuseffectivediameterofbundledconductoris muchlargerthanthat of normal conductor.

Bundledconductor lineswill havehigher capacitance andlowerinductance than ordinary lines they will have higher Surge Impedance Loading ($Z= (L/C)^{1/2}$). Higher Surge Impedance Loading (SIL) will have highermaximum power transfer ability.

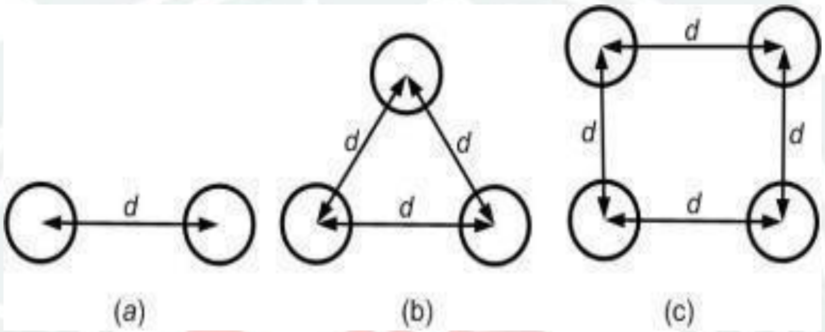

Figure1.5Showsthatbundledconductorconfiguration

StandardConductors

These kinds of conductors are defined as standard because you can find them on international normative(EN50182, ASTMB231, B399,B232). Strandedwireiscomposedof anumberof smallwires bundledor wrapped together toform alargerconductor.Strandedwireismore flexible than solid wire of the same total cross-sectional area. Standard conductor is very much popularin powersystemfortransmission anddistributedline.Itis usedto reduce theskin effect.

ConductorMaterialsforOverheadLines

ElectricalandMechanicalProperties:

Thefunctionofoverheadlinesistotransmitelectricalenergy.Theimportantpropertieswhich the line conductors must have are:

- Highelectricalconductivity.
- Hightensilestrength.

- Lowdensity.
- Lowcost.

Bundling of conductor increases the electrical andmechanicalpropertiesincomparisontothe solidconductors.Itiscalledasstranding.Thenumberofstrandsincablesare7,19,37,61,91, 127or169astheseconductorsgivethecylindricalformation.

Copperconductorusedfortransmissionishard-drawncopper.

Properties:

- Ithasthebestconductivity.Ith
- ashighcurrentdensity.
- The metal is quite
- homogeneous.It has low specific
- resistance.

1.10HighResistivityMaterial

Highresistivitymaterialpossessingveryhighvalueof resistivity

- Lowtemperatureco-efficient
- Highmechanicalstrength
- Longservicelife
- Lowcostandeasilyavailableinmarket
- Highmeltingpointtowithstandhightemperature

Example: Tungsten,Carbon,Platinum,Mercury

HighResistivityMaterialsandtheirApplications:

Tungsten

Properties:

- It is grayish in colourwhen in metallic form. It
- has a very high melting point (3300ºC)
- It isavery hardmetal anddoes notbecome brittleat high temperature.It can
- be drawn into very thin wires formaking filaments.
- Itsresistivityisabouttwicethatofaluminum.
- Initsthinnestform,ithasveryhightensilestrength.
- It oxidizes very quickly in the presence of oxygen even at atemperature of afew hundred degrees centigrade.
- Intheatmosphereofaninertgaslikenitrogenorargon,orinvacuum,itwillreliably workupto2000ºC.

Figure1.6Tungstenusedasfilamentinbulbs

Applications:

It isused asfilamentsofelectric lampsand asa heater inelectrontubes. It isalsousedin thermionic valves, radars. Grids of electronic valves, sparking and contact points.

Carbon

Carbonismostlyavailableasgraphitewhichcontainsabout90%of carbon.Amorphouscarbon is found in the form of coal, coke, charcoal, petroleum, etc.

Carbonisveryhighresistivitymaterial,generallycarbonaremanufacturefromgraphite.

Electricalcarbonisobtainedbygrindingtherawcarbonmaterials,mixingwithbindingagents.

Figure1.7Graphitepieces

Properties:

- Carbon has very highresistivity(about 4600micro ohm cm).It
- has negative temperature coefficientof resistance.
- It has a pressure-sensitive resistancematerial and has lowsurface
- friction.The current density is 55 to 65 A/cm^2.
- This oxidizes at about 300^{o}C and is very
- weak.It has very good abrasive resistance.
- Itwithstandsarcingandmaintainsitspropertiesathigh temperature.

Applications:

Carbonisusedbrushesofelectricalmachine,batteryandwelding.

1.10.3Platinum

Properties:

- Itisagrayish-whitemetal.
- Itisnon-corroding.

- Itisresistanttomostchemicals.
- Itcanbedrawnintothinwiresandstrips.
- Itsmeltingpointis 1775^{o}C.
- Itsresistivityis10.5microohmcm.
- Itisnotoxidizedevenathightemperature.

Applications:

- Itisusedasheatingelementinlaboratoryovensandfurnaces.
- It is used as electrical contactmaterial and as amaterial forgrids in special-purposevacuum tubes.
- Platinum-rhodiumthermocoupleisusedformeasurementoftemperaturesupto1600^{0}C.

1.10.4Mercury

Properties:

- It is good conductor of heat and
- electricity.It is a heavy silver-whitemetal.
- It istheonly metal whichisliquid at roomtemperature.Its
- electrical resistivity is 95.8micro ohm cm.
- Oxidationtakesplaceifheatedbeyond3000Cincontactwithairoroxygen.
- Itexpandsandcontractsinregulardegreeswhentemperaturechanges.

Figure1.8Mercuryvapourlamps

Applications:

Mercury vapourlamps,mercuryarc rectifiers,gas filled tubes; formaking and breaking contacts; used in valves, tubes, liquid switch.

Cable

ElectricalandMechanicalPropertiesofCables:

Cables are most useful for low-voltage distribution in thickly populated areas. The advantages of cables are: The cable transmission is not subjected to supply interruption caused by lightning or thunderstorms, birds and other severe weather conditions. It reduces the accidentscausedby breaking of the conductors.

RequiredPropertiesofCables:

- Highinsulationresistance.
- Moisture and water percolated due torain orothercauses should not come in contactwith conductor.
- Lowdischargecurrent.
- Resistanttochemicalactionduetochemicalcontentinearthordamagesduetoinsects.
- As thereis notmuch opportunity forheat dissipationfrom conductor, the insulatormust be capable of withstanding, without any change in qualities, the temperature within thecable.
- Itmustbeflexible,lightandoccupylessspace.
- Available in right quantity and at low rate. Materials Used for Manufacturing Cables are Paper (impregnated, vulcanized bitumen, rubber, compressed air, petroleum jelly, metal sheath (lead orlead alloy), galvanizedsteel or tapes for armoring and jute.

Figure1.9Showsthoseelectricalcables

Superconductor

Historically,the first superconductor tobediscoveredwasmercury-discoveredbyKimberling Ones in1911. The bestconductors like silver,copper andgold are notsuperconductors.

Superconductivitydependson:

- Electron-protoninteraction,andCriticaltemperature.

They aresomemetalandchemicalcompoundswhoseresistivityiszerowhenthesetemperatures is near 0^0 Kelvin and this stage such metal is calledsuper conductivity.

Thetransitionfromnormalconductivityto superconductivitytakesplacealmost suddenly.It occurs very narrow range of temperature.Super conductor is two types:

- SoftConductorand
- HardConductor

A largenumber of metals andalloysare superconductors, with critical temperatures$T_c$ranging from less 1K to 18K. Even some heavily doped semiconductors have been found to be superconductors.

TypeIsuperconductors are thosesuperconductorswhichloosestheirsuperconductivityvery easily or abruptly when placed in the external magnetic field. TypeI superconductors arealsoknown as **soft superconductors** because of this reason that is they looses their superconductivity easily

TypeIIsuperconductorsarethosesuperconductorswhichloosestheirsuperconductivity gradually but not easily or abruptly when placed in the external magnetic field. Type II superconductors are also known as hard **superconductors**

Applications:

- Superconductors can be used for the production of strong magnetic fields. Magnetic inductions in the order of 10 Wb/m^2, far above the largest value obtainable with iron-core electromagnets, have been obtained in superconducting Solenoids.
- Superconductors are based on the effect of an applied magnetic field on thetransition between normal andsuperconducting states. e.g. at a constant temperaturebelowTc, changes back and forth from normal tosuperconducting behaviorcanbeaffectedby varying the external magnetic field, which thereby can control the current in a circuit connected to the superconductor. Thus, amplifiers, oscillators, control systems,andespecially the logic and information storage functions of a large-scale computer can be provided by the controlling magnetic field exercises on superconductivity.
- Super conductingmaterial is used for powercablewillenable transmissionofpowerover a long distance using a diameterof few centimeterwithout any powerloss.
- Superconductorscanperformalifesavingfunctionisinthefieldofbiomagnetic.

LowResistivityCopperAlloy

Wehave notice earlier that copper becomes mechanically hard whenitisdrawnhowever hardeningof copperis also combination of othermetal brass,bronze,beryllium copperalloys.

Brass

When copper is alloyed with zinc called brass. The proportionsof zinc andcoppercan vary tocreate different types of brass alloys withvaryingmechanicalandelectrical properties,ithaslower conductivity then copper .it is wieldable.

Application:
Itis usedinmanufactureofswitches,lampholderetc.

Bronze

Bronzeitisan alloy consistingprimarilyof copper,commonly with about12%tin andoften withtheadditionofothermetals(suchasaluminum,manganese,nickelorzinc)andsometimes non-metals ormetalloids such as arsenic,phosphorus orsilicon.Brass is analloyof copperand zinc. Bronze is ametal alloy consisting primarily of copper,usually with tin as themain additive, but sometimes with other elements such as phosphorus, manganese, aluminum, or silicon. Higher malleability than zinc or copper.

Applications:

SwitchBlade,SlidingContact.

1.13.3BerylliumCopperAlloy

The copperalloy containing a beryllium is calledas a beryllium copperalloy.Ithashigh mechanicalstrength.Ithashighmechanicalstrength.Itisusedformakingcurrentcarrying spring, brush holder, sliding contact. It has many specialized applications in tools for hazardous environments,musical instruments,precisionmeasurement devices, bullets,andaerospace.

Berylliumalloyspresentatoxicinhalationhazardduringmanufacture.

Applications:

KneifandSwitchBlade.

MODELQUESTIONS	
1.	Whatisthedifferencebetweenlowresistivitymaterialandhighresistivitymaterial?
2.	Whatissuperconductor?
3.	Writethepropertiesandapplicationoflowresistivitymaterial?
4.	Writethepropertiesandapplicationoflowresistivitymaterial?
5.	Whatdoesumeanbyresistivity?

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2

Chapter

SEMICONDUCTINGMATERIALS

Introduction

“A semiconductor material is one whose conductivity lies between that of a conductor and an insulator.” The two most commonly used semiconductor materialsaregermaniumand silicon, Atom is the smallest practical which consists of proton electron andneutron.

Conductor:

Itisthosesubstancesinwhichelectriccurrentpassthrougheasily.

Example:Silver,iron,cu,gold,Al,humanbody,earth,salt.

- Forbiddenenergygap=0ev.
- Positivetemperaturecoefficient(TαR)iftemperatureincreasesthenresistance increases and if resistance increases then temperature increases.
- In termsofenergybandasthevalenceandconductionbandsoverlapeachotherdueto this overlapping; aslight potential differenceacrossaconductorcausesthefree electrons to constitute electric current.

Semi-conductor:

Itisthosesubstancesinwhichareliesinbetween ConductorandInsulator.

Example:Si,Ge

- Forbiddenenergygap=1ev
- Negativetemperaturecoefficient so(Tα1/R)iftemperatureincreasesthenresistance decreases and if resistance increases then temperature decrease.
- Intermsofenergyband,thevalencebandisalmostfilledandconductionbandisalmost empty.

Insulator:

Itisthosesubstancesinwhichelectriccurrentcannotpassthrougheasily.

- Example:Glass,wood,dry,air,mica,sulphur,wax,oil.
- Forbiddenenergygap>8evor15ev.
- Zerotemperaturecoefficient(T=0).
- Intermsof energyband, the valenceband isfull while theconductionbandisempty Proton +, Electron- , Neutron +_

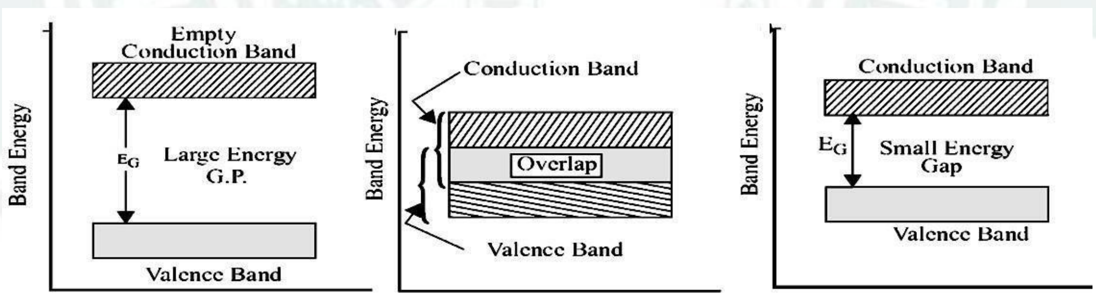


Figure2.1Energybanddiagramsofinsulator,conductorandsemi-conductor

2.2 SimplifiedSiandGeAtoms

The electricalcharacteristics of asemiconductorfallbetween those ofaconductorandan insulator.A semiconductorhas 4 electrons in its valence ring(outmost orbit).A goodinsulator has8electronsinitsvalencering.Thebestconductorhasoneelectroninthevalencering.The twomostwidelyusedsemiconductorsaresilicon(Si)andgermanium(Ge).Theiratoms structure is shown in belowfigure 2.2.

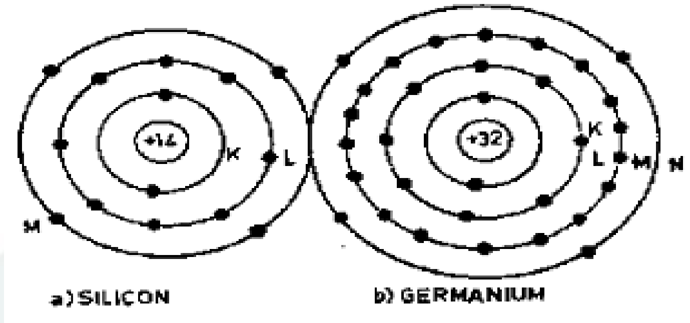


Figure2.2ShowsthatatomsstructureofSiandGe

The electricalcharacteristics of asemiconductorfallbetween thoseofaconductorandan insulator.A semiconductorhas 4 electrons in itsvalencering(outmostorbit).A goodinsulator has 8 electrons in its valence ring. The best conductorhasoneelectronin thevalence ring. The two most widely used semiconductors are silicon (Si) and germanium (Ge).

InterAtomicBonds

Covalent bond: it is a chemical bond. It is also called molecular bond. It involves the sharing of electron pairs between atoms.These electron pairs areknown assharedpairsorbondingpairs, andthestablebalanceofattractiveandrepulsiveforcesbetweenatoms,whentheyshare electrons, is known as covalent bonding.

Carbon**and**oxygencombinetoformcarbondioxide(CO_2)

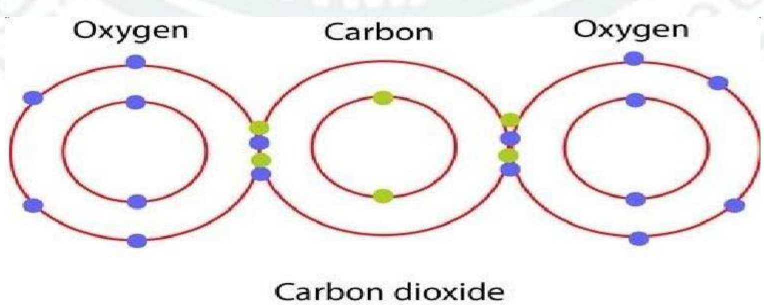


Figure2.3CovalentbondformationofCO₂

Covalent bonds are formed between non-metal atoms. Each of the atoms involved in bonding contribute one-two, three or more electrons to form the shared pair.

Ionicbond: Ionicbondingisatypeofchemicalbondingthatinvolvestheelectrostatic attraction between oppositely charged ions, and is the primary interaction occurring in ionic compounds

Forexample,whensodium(Na)andchlorine(Cl)arecombined,thesodiumatomseachlose an electron, forming cations(Na^+), and the chlorineatomseach gain an electron to form anions(Cl^-)

$$Na+Cl \rightarrow Na^+ + Cl^- \rightarrow NaCl$$

Metallic bond: Metallic bonding isthe force ofattraction between valenceelectrons andthe metal atoms.It is thesharing of many detachedelectrons betweenmany positive ions.

Semiconductoristwotypes

- Intrinsictypesemi-conductor
- Extrinsictypesemi-conductor

IntrinsicConductor

- Itisapureformofsemiconductor.
- Herenumberofelectronsisequaltonumberofholes.
- Itsconductivityislow,Examples:Si,Ge.
- ItisalsocalledasanUndoppedsemiconductor.
- Ifitstemperatureisbroughtdownto0°Kthisintrinsicmaterialareasagoodinsulator and very little amount of currentwill flow through it.

Extrinsic Semiconductor

- Itisimpureformofsemiconductor.
- Herenumberofelectronisnotequaltonumberofholes.

- Itsconductivityismore,Examples:P-type;N-type.
- Extrinsicsemiconductoristwotypes1)P-typesemi-conductor;2)N-typesemiconductor.

DifferencebetweenSiandGeSemiconductor

Si	Ge
Itis cheaper	Itiscostly
HighPeakinversevoltage	LessPeakinversevoltage
IthashighKneevoltage-0.7	Ithas lesskneevoltage-0.3

2.7 DifferencebetweenP-TypeandN-TypeSemi-conductor

P-TypeSemiconductor	N-TypeSemiconductor
p-type semiconductor is prepared by additionoftrivalentimpurities	n-type of semiconductor is prepared byaddition of pentavalentimpurities
Toobeyoctet rule acceptoneelectron fromanotheratom	Toobeyoctetruledonateoneelectronto another atom
p-type semiconductor majority charge carrierisholeandminoritychargecarrier is electron	n-typesemiconductormajority charge carrieris electron andminority charge carrier is hole
it is also called accepter type semi conductor	itisalsocalleddonnertypesemiconductor

2.8 N-typeMaterial

Whenapentavalentimpurityisaddedtoanintrinsicmaterialsuchassiliconorgermanium,only four of its valence electronslock into the covalent bond formation of atom structure. The fifth valenceelectronof theimpurity atomisfreetowanderthrough thecrystal.Showstheadditionof an atom of arsenic as an impurity. The impurity atom becomes ionized and has a positive charge when its fifth electron moves away. The positive impurity ion is not free but is firmly held in the crystalstructure.Thepentavalentatomdonatesanextraelectronandiscalledadonorimpurity. A material doped with a donor impurity has excess of electrons in its structure. It is called N-type material.ThenetchargeofN-typematerialisstillnaturalsincethetotalnumberofelectronsis equal to the total number of protons. Arsenics impurity atom provides a fifth electron that cannot enter a covalent bond structure.

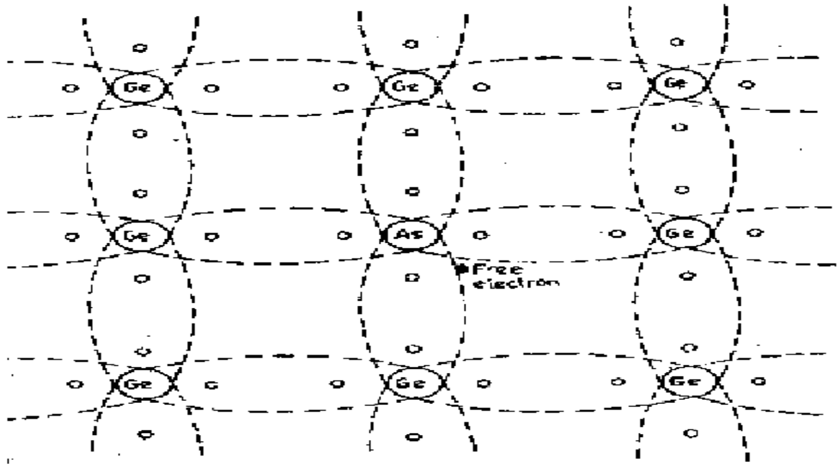


Figure2.4Arsenicimpurityatomprovidesafifthelectron

P-typeMaterials

When a trivalent impurity isadded to theintrinsicmaterial, the two lock into acrystal structure.Theimpurityhasthreevalenceelectrons.Thereisaholeinthecovalentbondstructurecreated by thelackofan electron.Theholerepresents anincompletecovalentbondandexhibitsa positive charge. In order to complete the bond and from a stable 8 -electron structure, a valence electronfromanearbyatomgainssufficientenergy tobreakloosefromitsbondandjumpsinto theholeduetoits attraction.Therefore,this typeofimpurityiscalledan“acceptor”.The electrons available to fill thehole and complete the bondhave been release by the nearby atom whose bonds have been broken andhole created.Thus,the processwillcontinuecreatinga mobility of holes. The impurity atom Arsenic impurity atom provides a fifth electron becomes negatively ionized as accepts an electron. The germanium or silicon atomwhich releasesone electron becomes positively ionized.Thenet charge of thematerialisstillneutral.Thetotal number of electrons is equal to the total number of protons.

SemiconductorsCommonlyUsed

Thefollowingmaterialsarecommonlyusedassemiconductors:

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

(v)Phosphorus (vi)Arsenic (vii)Antinomy (viii)Sulphur
(ix)Selenium (x)Tellurium (xi)Iodine

Givefiveexamplesofsemiconductoranditsapplications:

1. **Silicon:**Itisusedinprocessingandmanufacturing
2. **Germanium**:Itisusedinthermalsensitivepurpose
3. **SiC:**ItisusedinLED
4. **Diamond:**Itisusedforcuttingpurpose
5. **GaAs**:Itisusedinhighspeeddevice.

WorkingandApplicationofSemiconductors

Semiconductormaterialsareusedin:

- Rectifiers
- Temperature-SensitiveResistors
- PhotoconductiveAndPhotovoltaicCells
- Varistors
- HallEffectGenerators
- StrainGauges
- Transistors

Rectifiers(Whichconvert'sDCtoAC)

(a) GermaniumandSiliconRectifiers:

Whena P-type material andanN-typematerial are joinedtogether, theyformajunctioncalled P- N junction.When an externalvoltage isappliedacrossthetwomaterial,aflowof current results ifthepositiveandnegativeterminalsofthevoltagesourceareconnectedrespectivelytothe ends of the P and N material. The voltage applied this way is called "forward-biasing" the P-N junction. If the appliedvoltageisreversed, that is,the positiveofthesupplyvoltageis connected to N side and negative of the supply is connected to the P side, there isnoflowofcurrent.Thisis called"reversebiasing".Thus theP-Njunctionoffershighconductivitywhen forwardbiasedandno conductivitywhenreverse biased.Thus, the semiconductorcanbe used as a rectifier. The modern P-N junction rectifiers use germanium orsilicon material.

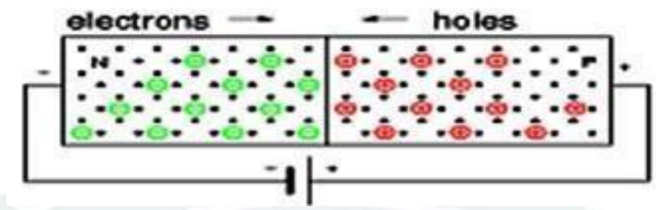


Figure2.5ForwardbiasedconditionofGermaniumandSiliconRectifiers

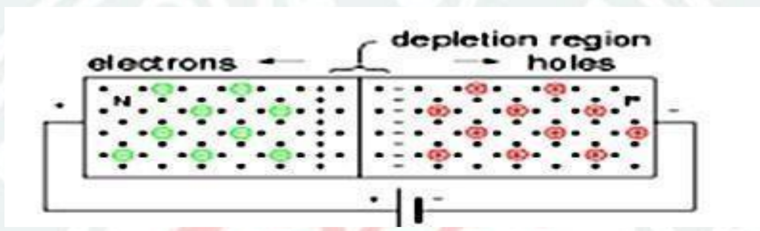
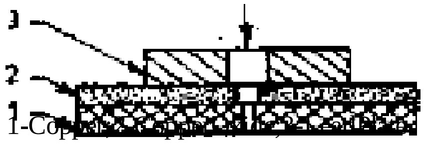


Figure2.6ReversebiasedconditionofGermaniumandSiliconRectifiers

(b) CopperOxideRectifier:

The earliestsemiconductor to be used was copper oxide. Its application was incopperoxide rectifier.Copperoxide rectifieris a placeof 99.98 %purecopperon which afilmof cuprous oxide is produced by a special process. From one side of the plate, cuprous oxide is cleaned and electrode is soldereddirectly to the copper. Thesecondelectrodeis solderedto cuprousoxidefilm. When a positive potential is applied to the oxide layer and negative to thecopper,it corresponds to forward biasing of a P-N junction. By arranging thecopperplate.Elementsinstacks, rectifiers foruse in many kinds ofmeasuringinstrumentsandcircuits can be obtained. These rectifiers have low permissiblecurrentdensity.They arenotusedforpowersupply purposes. To have a good contact with copper oxide, a lead plate is pressed against it. The two terminals of the rectifiersare the copperplate and leadplate.The oxide will be in between theplates as shown in figure2.7.This rectifierwillallowthecurrenttoflowonly fromoxideto copper and will not allow flow from copper to oxide. The voltage that may be applied to a single rectifier ranges between 4 and 8 V,so anumber of units are connected in series foroperatingon high voltages.Similarly,parallelconnectedof theunits,increases thecurrentratingofthe rectifiers,asthemaximumcurrentdensityintheforwarddirectionis0.1to0.15A/cm^{2}atan allowablevoltageof8V.Thelifeofcopperoxiderectifiersis12to15yearsandefficiencyis 70%.



1-Copper;2-CopperOxide;3-LeadPlate

Figure2.7CopperOxideRectifiers

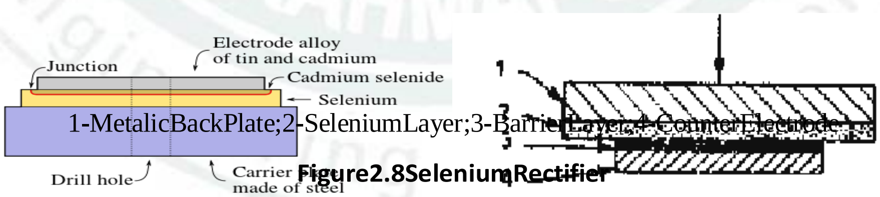
Applications:

Thesetypesof rectifiersaremostlyusedformeters,battery cellcharging,X-rayworks, measuring instruments, railway signaling, telecommunication systems, etc.

(c) SeleniumRectifiers:

Inthistype,afilm of 0.5mm.thicknessisdeposited ononesideofthemetallic back plate (iron or aluminum). By means of chemical treatment, a film of “blocking” or “barrier” layer is formed between selenium and counter electrodes.

Therectificationis from backplatetoselenium.Therectifierconstructionisasshownin A single unit can sustain 6 V. The normal current density is about 0.04 A per cm^2 for full wave rectification.Thepowerefficiency is 50to75%.Theunits canbecombinedinseriesorin parallel, similar to that of copper oxide rectifiersto work at desiredvoltage or for the required current capacity.



1-MetalicBackPlate;2-SeleniumLayer;3-BarrierLayer;4-CounterElectrode

Figure2.8SeleniumRectifier

Applications:

This type of rectifiers are widely usedfor battery charging,telegraphandtelephonecircuits, control circuits, railway signaling, meters, electroplating and other works.

Suchrectifiersareavailableincapacitiesofupto50to100KW.

Temperature-sensitiveElements(Thermistors)

Ifthetemperatureofasemiconductormaterialis increased,thatcausesadecreaseinits resistance.This property is usedin temperaturesensitiveelements whicharecalledas “thermistors‟. Thermistors are non linear device.

Thermistor is a negative temperature device ie NTC (T α 1/R) if temperature increasesthen resistance decreases.The termistorsare thermally sensitive material (resistors).They aremadefrom oxides of certain metals such as copper,manganese, cobalt, iron and zinc.

AdvantagesofThermistor:

- Itisasmallsizeandlowcost
- Fastresponseoveranarrowtemperature
- Itsweightisalsoless

ApplicationsofThermistors:

Thermistors find application in temperature measurements and control. They sense temperature variations and convertthesevariations into an electricalsignalwhich isthenusedtocontrol heating devices.

Thermistorsarealsousedformeasurementofradiofrequencypower,voltageregulation.

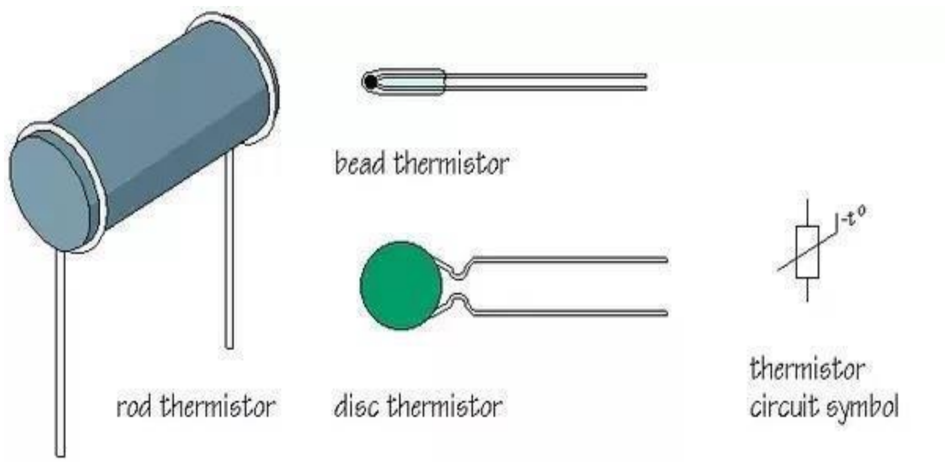


Figure2.9Different Typesof Thermistor

PhotoconductiveCells&PhotovoltaicCells

(a) PhotoconductiveCells

Photo conductive cell isa two terminal semiconductor device .it isalso called asphoto resistivecell. The resistance of semiconductor materials is low under light and increases in darkness. Photoconductivecellscanbeusedinapplicationswhichrequirethecontrolofacertainfunction or event according to the colour or intensity of light.

Applications:

- Theyareusedinburglaralarms,flamedetectorsandcontrolforstreetlights.
- Itisusedinsensorswitch
- Itisalsousedinsmokedetector

(b) PhotovoltaicCells

- ItisalsocalledasPVCell
- Itisalsocalledphotovoltaiccell
- Itconvertslightintoelectricalenergy

WhatisSolarEnergy?

It is thecombinationof light andheatis producedby sun is known asasolarenergy .so there are lot of application in solar cell

- Photovoltaic cells are devices that develop andemf when illuminated.They convert lightenergy into electrical energy.
- Solarcellisdevelopedintheformofsliceofsinglecrystalsilicon.
- Typicalsizeofsolarcellis20mm ×20mm ×300mm.
- Theoverallefficiencyofsolarcellisabout10to20%.

Applications:

Theapplicationsofphotovoltaiccellsareinphotographicexposuremeters,lightingcontrol systems,automaticaperturecontrolincameral.

Figure2.10SolarCell

2.11.4Varistors

Varistorisavoltagedependentresistor.Invaristortheresistancedecreaseswhenvoltage increases, theword composedof thevariable resistor.The resistanceofsemiconductors varieswiththeapplied voltage.Thispropertyisusedindevices calledvaristors.The most common typeofVDRisMOV(metaloxidevaristor).

Applications:

- Theyareusedinvoltagestabilizerandusedformotorspeedcontrol
- Varistorareusedinpowersupplysystem
- Varistorareusedastelephoneandothercommunicationlineprotection

HallEffectGenerators

Whencurrentflowsthroughasemiconductorbarplacedinamagneticfield,avoltageis developedatrightanglestobothcurrentandthemagneticfield.Thisvoltageisproportionalto thecurrentandtheintensityof themagneticfield.Thisiscalledthe“Halleffect”.

Consider the semiconductor bar shown in Figure 2.11, which has contacts on all four sides. If a voltageE_L is appliedacross thetwooppositesidesA andB_2acurrentwillflow.If thebaris placed perpendicular to magnetic field B as shown in the figure, an electrical potential EH is generatedbetweentheothertwocontactsCandD.ThisvoltageEHisadirectmeasureofthe magneticfieldstrengthandcanbedetectedwithasimplevoltammeter.

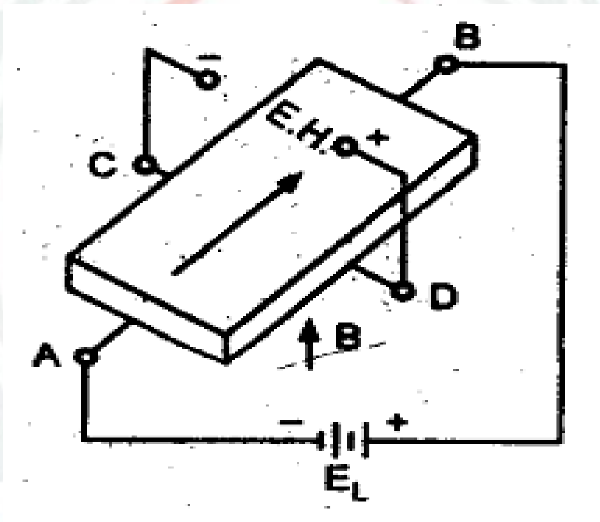


Figure2.11HallEffectgenerators

Application

TheHallEffectgeneratorsmaybeusedtomeasuremagnetisfields.Itiscapableofmeasuring magneticfieldstrengths that havestrength of 10-6of themagnetic fieldof theearth.

StrainGauges

Astraingage(sometimesreferredtoasaStraingauge) isa sensor whoseresistance varieswith appliedforce.Itconvertsforce,pressure,tension,weight,etc.,into achangein electrical resistancewhichcanthenbe measured.Astheirnameindicates,they are used for the measurement of strain.

Gaugefactor= $\frac{\Delta R/R}{\Delta L/L}$

Applications:

Straingaugesareusedtofindthesmallchangesinlengthofsolidsubstancesorobjects.

Transistors

Itisathreeterminal,twojunctiondevice:AtransistorconsistsoftwoPNjunctionsformedby sandwiching either P-type or N-type semiconductor between a pair of opposite types.

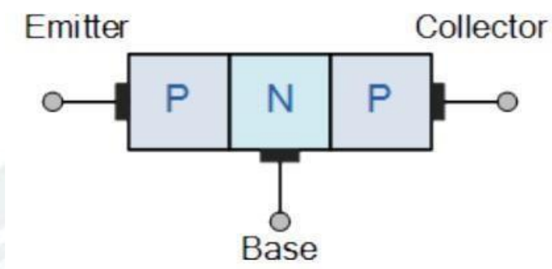


Figure2.12PNPtransistor

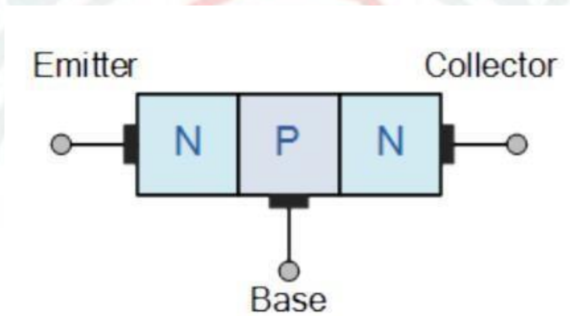


Figure2.13NPNtransistor

Transistorisusedasanamplifier.Itactsasaswitch.Ithavethreeregion:

- cut-offregion
- active region
- saturationregion

Transistorisaunilateraldevice.

Transistorisclassifiedintotwotypes:

1. BJT(BipolarJunctionTransistor)

- Itis athree terminaldevice.Itis acurrentcontrolleddevice.Itis bipolarbecause two polarities is responsible for current conduction. (Electron and holes).
- Itsthreeterminalsareemitter,baseandCollector

2. **FET(FieldEffectTransistor)**

- It is athreeterminal device.It is avoltagecontrolleddevice.Itisaunipolar devicebecauseonepolaritiesisresponsibleforcurrentconduction.(Either electron or holes) its three terminals are gate, drain and source

DifferencebetweenBJTandFET

BJT	FET
Itisacurrentcontrolleddevice	Itisavoltagecontrolleddevice
Ithashigherswitchingspeed	Ithashigherswitchingspeed
ItisLongerLifeandHighefficiency	ItisshorterlifeandLowefficiency
It is bipolar because two polarities is responsibleforcurrentconduction.(electron andholes)	It is aunipolardevice because one polarities is responsibleforcurrentconduction. (Either electron or holes)
Itsthree terminals are emitter, base and Collector	Itsthreeterminalsaregate,drainandsource

Currentamplificationfactor:

B = $\Delta Ic/\Delta I_B$ (in AC) but in dc $\beta = Ic/I_B$ so $Ic = \beta I_B$A

$=\Delta Ic/\Delta I_E$

Relationshipbetweenβandα

A = β/1+ β β = output current/input current

β = α/1- α

Figure2.14Transistor

Advantages:

- Usuallysmallersize,lowercostandlongerlife.
- Canhandlesmallcurrent.
- Canbecombinedinthemillionsononecheapdietomakeanintegratedcircuit.
- Lowerpowerconsumption,lesswasteheat,andhighefficiencythanequivalenttubes, especiallyinsmall-signalcircuits.
- Canoperateonlower-voltagesuppliesforgreatersafety,lowercosts.

Disadvantages

- Maintenancemoredifficult;devicesarenoteasilyreplacedbyuser.
- Semiconductorscommonlyused.

MODELQUESTIONS
1. Whatis the difference between conductorandsemiconductor?
2. What is strain gauge?
3. What is p-type material?
4. What is Transistors?
5. Whatisgaugefactor? What
6. is PV cell?
7. WhatisHallEffectDCGenerators?

3

Chapter

INSULTINGMATERIALS

Introduction

For safe and satisfactory operation of all electrical and electronics equipment insulator plays important role. Basically current carrying wires, surfaces need to be cove red withinsulating material. Letus see thestructure of thematerial on the basisof energy band.In thistype of material, the highest occupied energy band (Valence Band) is completely filled. The nexthigherband (Conduction Band) is quite empty. The gap between these two bands is too large. When the electric field is applied across these materials, the electrons from valence band cannot reach the conduction bandand conduction of electronstops. Suchmaterialsareknownasinsulators. Diamond is an example of this kind of material witha separation of nearly 6eV between valence band and conduction band.

InsulatingMaterialsforElectricalEngineering

The insulating materials used forvarious applicationsin electrical engineeringare classifiedin three categories:

1. **Solidinsulatingmaterial**
2. **Liquidinsulatingmaterial**
3. **Gasesinsulatingmaterial**

1. **SolidInsulatingMaterial:**
   - Fibrousmaterial
   - Impregnatedfibrousmaterial
   - PVC
   - Rubbermaterials
   - Glass materials
   - Mineralmaterials
   - Ceramicmaterial
   - Non–resinousmaterial
2. **LiquidInsulatingMaterial:**
   - Mineral oil (kerosene oil, alcohols, lubricating oils,waxes etc) Synthetic
   - liquids
   - Vegetableoils(obtained fromseedsofcotton, sunflower, soybean,pulp, etc)
   - Fluorinated liquids
   - Siliconfluids
   - Vaseline
   - Varnish
3. **GaseousInsulatingMaterial:**
   - Air
   - Nitrogen
   - Hydrogen
   - Inertgases
   - Halogen
   - Sulphurhexafluoride(SF_6)
   - Carbondioxide(CO_2)

ClassificationofMaterialsonthe basisofStructureofMaterial

- Fibrousmaterial(Wood,Paper,Cotton,AdhesiveTapes)
- Insulatingliquids(TransformerOils,CableOils,SiliconeFluids)

- Non-resinousmaterial(Bitumen's,Wax)
- Glassandceramics(Glass,Porcelainetc.)
- Plastics(MoldingPowder,Rubberlaminations)
- Mineral(Mica)
- Gaseous(Air,H_2,N_2,Ne,CO_2,SF_6,HgandNavapor)

FibrousMaterial:

These areobtainedfromanimaloriginorfromcellulose whichis themain constituentof vegetables plants .the following materials are:

1. Wood

- High dielectric constant,Highly hygroscopic,dry woodcan bearaVoltage gradient of 10kV/inch
- Wood is naturallyavailablematerial and obtainedfromtrees It is
- a good insulating material
- Itisusedforlowvoltageonly
- It isused for wooden switch boards
- It is light in weight
- It is easily available in nature
- Its working temperature is low
- Itisusedinswitchboards,terminals,casingandcapping,itisusedininstrument andequipmentsetc.

Figure3.1WoodSwitchboards

Applications:

Terminalblock,wedgesofarmaturewinding,operatingrodsinhighvoltageswitch gears,Cardboard, electrical wood poles areusedfortransmissionanddistributionof electric power.

2. **Cardboard**

- Itissimilartopaperbutonlydifferenceisthatitisthickmadebywoodpulp through a calendaring machine
- Itsthicknessismorethanpaper
- It isstrong
- Itisless effective
- It islessflexible
- Itisusedinswitchboard.

Applications:

Itisusedinswitchboards,terminals, casingand capping,itisusedininstrumentand equipments, round box in house wiring etc.

3. **Asbestos**

- Itisamineralfibrousmaterial
- Itcanwithstandveryhightemperature
- ItisavailableinKadapadistrictofAndhraPradesh
- Itcanbeuseduptoavoltage 33kv
- Itisstrong andflexible

Applications

Asbestosfindapplicationin electrical equipment andmachine,itis usedin electric board, Itisusedinheatingdevicelikeoven,electricoven,panelboardconstructions,itisused inroofsofbuilding.

Figure3.2Asbestos

ImpregnatedFibrousInsulatingMaterial:

- Impregnatedpaper
- Mineralinsulatingmaterials
- Ceramicinsulatingmaterials
- Glassinsulatingmaterials
- Plasticinsulatingmaterialsorinsulatingresins

1. Rubber

- Stretchable,Moisturerepellant,
- Goodinsulatingproperties,
- Good corrosion resistance.Can be obtained as hard rubber, synthetic rubber, butadiene rubber, butyl rubber, chloroprene rubberand silicon rubber.
- Itisbasicallyusedincableforinsulationpurpose.
- Itisainsulatingmaterials.
- Itisahardandbrittle.

Applications:

Used as protective clothing such as boots and gloves, also used as insulation covering for wires and cables. Hard rubber is used in housing forstoragebatteries,panelboard, jacketing material.

2. **PolyvinylChloride(PVC)**

- Itisobtainedby polymerizationofvinylchlorideinthepresenceof acatalystat 500^0C. PVC exhibits good electrical and mechanical properties.
- Itishard,brittle,andnon-hygroscopicandcanresistflameandsunlight.
- PVC used as insulation material fordry batteries,jacketingmaterial forwires and cables.

Properties:

- Itishard
- Itisrigid
- Itislessweight
- Itischeep
- Itisobtainedindifferentcolour
- Itsdielectricconstantis5to 6
- Ithasgoodmechanicalandelectricalproperties
- Itcanwithstandveryhightemperature(above80^0C)
- Itsinsulationresistanceis$10^{12}$to 10^{13}ohm-cm
- Itisslightlyhygroscopic
- Itsdielectricstrengthis15KV/mmto30KV/mm
- Itnevergets corrosion
- Itisnormallytransparent,brittleandhard

Applications:

- Itisusedinwireandcable
- Itisusedindrybatteries
- Itisusedinpipesinelectricalwiringsystem
- PVCcablearecommonlyusedinlowandmediumvoltage
- PVCWireisusedinradio,television,aircraftsystem

Figure3.3PVCpipes

3. **EpoxyGlass**

Epoxyglassismadeby bonding twoormorelayerofmaterial.Thelayersused reinforcing glass fibers impregnated with an epoxy resin. It is water resistantandnot affected by alkalis and acids.

It is used as base material for copper-clad sheets used for PCBs, terminal port, instrument case etc.

4. **Bakelite**

It ishard, darkcolored thermosettingmaterial,which is a type of phenol formaldehyde. It is widely usedformanufacture of lampholders,switches,plugsocketandbasesand small panel boards.

5. **MICA**

Two kindof mica are usedas neutral insulatingmaterial in electrical engineering.Thoseare Muscovite mica and Phlogophite mica.

(a) MuscoviteMica:

- Thechemicalcompositionofmuscovitemicais$KAI_3SiO_3O_{10}(OH)_2$.

- It is translucent green, ruby,silver or brown and isstrong,toughand flexible.
- Itexhibitsgoodcorrosionresistanceandisnotaffectedbyalkalis.
- Itisusedincapacitorsandcommutator

(b) PhlogophiteMica:

- Thechemicalcompositionofthis,$KMg_3AlSiO_3O_{10}(OH)_2$.
- Itpossesseslessflexibility.
- Itisamber,yellow,greenorgreyincolour.
- Itis morestable,butelectricalpropertiesarepoorercomparedto Muscovite Mica. It is used in thermal stability requirements, such as in domestic appliances like iron, hotplates etc.

6. Polyethylene

- Itisobtainedbypolymerizationofethylene.
- The polymerization is performed in the presence of catalyst at atmospheric temperature and pressure around 100^oC.
- To obtain heat resistance property polythene is subjected to ionizing radiation. Polyethyleneexhibitsgoodelectricalandmechanicalproperties,moistureresistant and not soluble in many solvents except benzene and petroleum at high temperature.

Applications:

It is used as general purpose insulation, insulations of wires andcableconductors,inhighfrequency cables and television circuits, jacketing material of cables. Polyurethane filmsare also used as dielectricmaterial in capacitors.

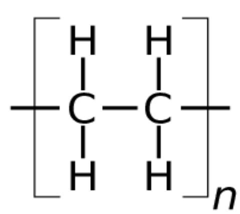


Figure3.5CrystalStructuresofPolyethylene

7. **Teflon**

The chemical name of Teflon is Poly tetrafluoroethylene. This is synthesized by polymerization of tetra fluro ethylene. It bears good electrical, mechanical and thermal properties. Its dielectric constant is 2 to 2.2,which doesnot changewith time,frequency and temperature. Itsinsulation resistance is very high and water resistant.

Applications:

It is usedasdielectricmaterials in capacitors,coveringofconductors andcables,asbase material for PCBs.

8. **Glass**

Glass is used in production of glass fiber. Glass is used as an insulatorfor x-ray tubes, electric bulbs, glass is employed for insulator in HEVH lines. Glass is used as a dielectric materials in capacitor.

LiquidInsulatingMaterial:PropertiesandApplications

1. **MineralOils**

Theoperatingtemperaturerangeof mineral oilis50-110^{0}C.Thesehydrocarbonoilsare used as insulating oils in transformers, circuit breakers,switch gears, capacitors etc.

- Intransformers,lightfractionoil,suchastransitoilisusedtoallowconvection cooling. Its high flash point is 130^{o}C, so it is able to prevent firehazard.
- Highly purifiedoilhasadielectricstrengthof 180kv/mmandif theoilcontains polar and ionizing material its dielectric loss increases.
- Theexamplesofmineraloilsarekeroseneoil,alcohol,lubricantoil.

2. **Askarels**

Thesearenon-inflammable,syntheticinsulatingliquids,usedintemperaturerangeof

50 – 110^{0}C. Chlorinatedhydrocarbons are themost widelyusedamongtheaskarels because of high dielectricstrength, lowdielectricconstant (4to 6)andsmall dielectricloss. They do not decompose under the influence of electric arc and have good thermal, chemical and electrical stability.

The most widely used hydrocarbons or Askarels are generally usedtoimpregnateacellulose insulating material, such as paper or press board etc., for its high breakdown strength.

3. SiliconFluids

Itis clearwaterlike liquid.It is usedin thetemperaturerangeof 90- 220^{o}Canditis clear, water like liquid. It is available in wide range of viscosity and stable in high temperature. They are non-corrosive to metal up to 200^{o}C and bear excellent dielectric properties in widerangeoftemperature.Soitisusedascoolantsinradiopulseand aircraft transformers.

4. FluorinatedLiquids

Thesearenoninflammable,chemicallystableoilsusedintemperaturerangeof50- 200^{o}C. They provide efficient heat transfer from the winding and magnetic circuits in comparison to hydrocarbon oils and used in smallelectric and radio devices,transformers etc. In presence of moisture electrical properties are deteriorated.

5. SyntheticHydrocarbonoils

Polybutylene, Polypropylene is the example of synthetic hydrocarbonoils.Theyhave similar dielectric strength; thermal stability and susceptibility to oxidation properties are Similaras that ofmineral oils.Theoperatingtemperature range is50-110^{o}C.These are used in high pressure gas filled cables and dc voltage capacitors.

6. OrganicEsters

These organic fluids are used in the temperature range of 50-110^{o}C. They have dielectric constant andvery low dielectric losses. The dielectricconstant rangesfrom 2to 3.5.

7. VegetableOils

It is obtained from seeds of cotton, sunflower, soybean pulp etc**.** These insulatingliquids have temperature rangeof 20-100^{o}C.Dryingoilsaregenerally suitablein theformation of insulating varnishes, while non-drying oils are used as plasticizers in insulating resin compositions.

8. Varnish

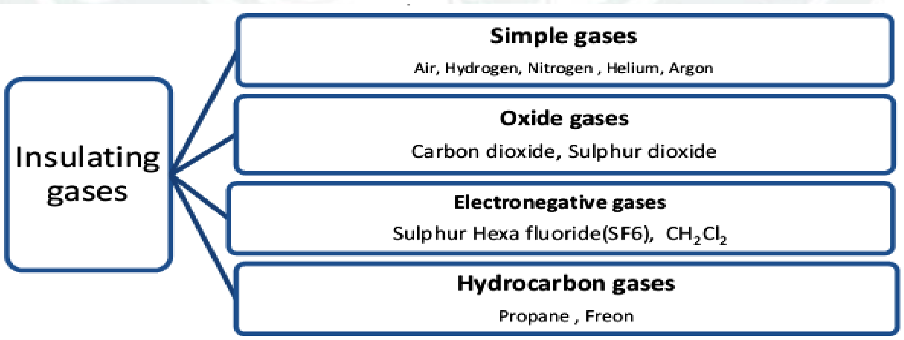
Varnish is a transparent. Itisa primarily usedin woodfinishing.It iscombination of drying oil, a resin and a thinner. It is the liquid form of resinous matter in oil or a volatile liquid.Hencebyapplying,itdriesoutbyevaporationorchemicalactiontoformhard, lustrouscoating,whichisresistanttoairandwater.

Itisusedtoimprovetheinsulationproperties,mechanicalstrengthandtoreduce degradationcausedbyoxidationandadverseatmosphericcondition.

3.5 GaseousInsulatingMaterials

Commonlyusedgaseousmaterialsare

1. Air
2. Nitrogen
3. Hydrogen
4. SF_6



1. Air

- Airisgaseousinsulatingmaterialanditisnaturallyavailable.
- Itformsabout80%ofearth‘satmosphereundernormalcondition.
- Itiscolourless

- Itisorderless
- Itistestless
- Itspermittivityis1
- Itsdielectricstrengthis30kv/cmat50hz
- Oxygeninairhelpsafire
- Itisreliableatlowvoltage
- Itcanoccupiesspace

Applications:

Airisneededtohearasound.Itcarriescloudtodifferentplaceandbeginningarain, Moving airis used to drive blades of wind mills.

2. Nitrogen

- Itisnonmetal
- Itischemicallyinert
- It is used in both chemical and electrical purpose
- It s dielectric strength is 3 to 5 kv/mm.

Applications:

Itisused incooling medium inselected gasininsulated transformer; it isusedasa fertilizer.

3. Hydrogen

- Itisrarelyusedasainsulator
- Atnormal temperature andpressure itis colourless,orderless andtest less It
- reactswithoxygen toform water(H_2O) andhydrogen peroxide(H_2O_2)
- Itiscommonlyusedincoolingpurposeinelectricalmachineduetoitslightness.
- Itsdielectricstrengthis2.5to4.5kv/mm

Applications:

It is used in cooling purposein electricalmachine,it isused in fuel anditisused to prepare tungsten filaments.

4. SF_6

- Sulfur Hexafluoride (SF_6) is, colorless, odorless. The electromagnetic gaseshave high dielectric strength compared to other traditional dielectric gaseslike nitrogen and air. The dielectric strength of SF_6 is 2.35 times more than air.
- More than 10,000 tons of $SF_6$are produced peryear,most of which (over8,000tons)
- Itisagaseousinsulatingmaterials
- Itisacolorless
- Itisaorderless

Applications:

SF_6 is mostly used in high voltage application and its use is most satisfactory in dielectric machines, like X-ray apparatus, Van de Graff generators, voltage stabilizers, high-voltage switch gears, gas lasers etc.

SF_6bearssomespecialpropertiesasfollows:

- SF_6 is colorless, nontoxic andnon-inflammable gas. It is the heaviestgas andhas low solubility in water. The gas can be liquefied by compression. Its cooling characteristic is better than air and nitrogen.
- Under normal temperature conditionsit is chemically inert and completely stable with high dielectric strength.
- This gas has very goodelectronegativeproperty.Itsrelativelylargemoleculeshave a great affinity for free electrons, with which they combine making the gas- filled break much more resistant to dielectric breakdown.

5. **Carbon Dioxide:** Carbon dioxide is used in certain fixed type capacitor and is used as a preimpregnate for oil filled high voltage apparatus, such as cable and transformers. The relative permittivity of carbon oxie is 1.000985 at 0^oC.

GeneralPropertiesofInsulating Material

The suitability of an insulating material for a specific purpose use can be decided by knowing its differentproperties.Sowehavetoknowtheexactrequirementoftheapplicationandthe requiredpropertyholdby theinsulatingmaterial.Basedonusesindifferentapplications following properties of materials are useful.

ElectricalProperties

The insulating material used in electrical or electronics appliances, should be considered for following:

- **InsulationResistance:**This is theohmicresistanceofferedbyaninsulationcoating, coverormaterialinanelectriccircuitwhichtendstoproducealeakagecurrentthrough the same with an impressed voltage across it.
- **Dielectric Constant or Permittivity:** The permittivity oftheinsulatingmaterialvarieswith temperature andfrequency in some cases.ThematerialslikeHCl,H_2O,CO, NH_3 have permittivity variation with change in temperature
- **Dielectric Strength:** It is themaximumimpressedvoltage bearingcapacity ofinsulator per unit thickness of material, up to which current does not flow through it. When current flows through the insulatoris known as dielectric failure.
- **Dielectric Loss:** Dielectric losses occur in allsolid and liquiddielectricdueto:a conduction current and hysteresis. The conduction current is due to imperfect insulating qualities of the dielectric and is calculated by theapplication of Ohm’s law. It is in phase with the voltage and results in the power loss (I^2R) in thematerial, which is dissipated as heat.Dielectrichysteresis is definedasthelaggingof electricfluxbehindtheelectric force producing itsothatundervaryingelectricforcesadissipationof energyoccurs. The energy loss due to above cause is called the dielectric hysteresis loss. The energy is dissipated as heat. This loss gives an indication of the amount of energy absorbed by the material, when subjected to AC fields.

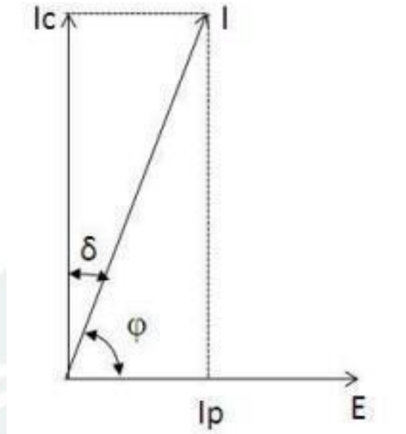


Figure3.6Plotof EagainstI$_c$

When a dielectric material is subjected to an ac voltage, the leakage current I does not lead the appliedvoltage$E$by exactly 90^0as shown invectordiagram the phase angleφis alwaysless than 90^o. The dielectricloss can becalculatedasfollows: Figure3.6 plotof E againstI_c

$$P = EI\cos\phi$$

$$\therefore P = E\frac{I_c}{\cos\delta}.\cos(90^o - \delta) = E\frac{I_c}{\cos\delta}.\sin\delta = EI_c\tan\delta = E.\frac{E}{X_c}\tan\delta.$$

Where$\phi = 90^o - \delta$and $I = \dfrac{I_c}{\cos\delta}$

Hence$P = E^2 2\pi fc.\tan\delta$.

δis thecomplementangletoφandis calleddielectriclossangle.tanδisthemeasureof dielectric loss known as dissipation factor.

VisualProperties

An insulating material possessing two opposite properties: transparency and thermal insulation is suitableincaseofreductionofenergyconsumptionforheatingandairconditioningand electrical energy savings. This is known as visual properties. Study of appearance, color and crystalline structure are the measures of this property.

MechanicalProperties

Mechanical properties such as tensile strength, impact strength, toughness, hardness, elongation, flexibility, mechanical strength, abrasion resistance etc. are to be considered for choosing the insulating material.

- **Mechanical Strength:** The insulating material shouldpossesssufficientmechanical strength torespondmechanicalstress.Mechanicalstrengthisaffectedbyfollowing factors.
  - **Temperature Rise**: It badly affects the mechanical strength of theinsulating material.
  - **Humidity**:Itistheclimaticeffectwhichaffectsalsothemechanicalstrength.
  - **Porosity**: An insulating material of high porosity will absorb more moisture and thereby affects the electrical properties as well as mechanical strength.

ThermalProperties

Following thermal properties are considered for selecting insulating material ofdifferent applications.

- **Thermal stability:** The insulatingmaterial must be stable (no change in physical state) within theallowedtemperatures.Certainmaterials likewaxandplasticgetsoftat moderate temperatures. So the mechanical property of the material is affected. Hence the operating temperature of thematerial is to be noted before its use.
- **Melting point**: The insulating material should have melting point (temperature bearing capacity without being melt), above that of operating temperature.
- **Flash point**: Thisis an important property of insulatingoils usedintransformer. Flashpointofaliquid insulatoris that temperature at which the liquid begins to ignite.
- **Thermal conductivity:** In electrical appliances heat is generated during operation, which shouldbe transferredtoatmosphere,tomaintaintheoperatingtemperaturewithinthe limit. Hence the insulators should have very low thermal conductivity.
- **Thermal expansions:** Rapid and repeated load cycle on electrical appliances cause correspondingexpansionandcontractionoftheinsulators.Inaresultvoidsarecreated

andaffectthe breakdown phenomenon.Thus twoinsulatingmaterialofdifferent coefficient of thermal expansion should be wisely selected.

- **HeatResistance:**Theinsulatingmaterialusedmustbeabletowithstandtheheat produceddueto continuous operationandremainstableduringtheoperation.Atthe same time it should not damage the other desired properties.

ChemicalProperties

Certainchemicalpropertiesarealsorequiredtobeconsideredfortheinsulatingmaterials.

- **Chemical Resistance**: It isthe abilityof theinsulatingmaterial tofight against corrosion in the presence of gases, water, acids andalkalis. Formaterialswhicharesubjectedto high voltage, high chemical resistance is also necessary.
- **Hygroscopity:** Many insulating materials are hygroscopic. Sometimes the insulation may come in direct contact with water. The porous materials are more hygroscopic than dense ones. Small amount of moisture absorbed by an insulating material affects its electrical properties drastically.
- **Moisture Permeability:** The tendency of an insulating material to pass moisture through them is known as moisturepermeability.Moisture canpenetrate throughvery small poresas the size of water molecule is very small. So this property is vital for selectingthe protective coating, cable sheaths etc.

Ageing

Ageing is the long term effect ofheat,chemical action andvoltage application.These factorsdecide the natural life of insulators and hence of an electrical apparatus. Insulation resistance decreases with age is known as ageing.For examples the lifeof underground cables is 40 to 50 years.Ifitisusedmorethanthelifeperiodthenthecablesgetshortedthenitwillbeadamage of other device.

MODELQUESTIONS	
1.	What is PVC?
2.	WhatisTeflon?
3.	WhatisWood?
4.	WriteGeneralPropertiesofInsulatingMaterial?
5.	What is Rubber?
6.	WhatisSF$_6$gas?
7.	WhatdoyoumeanbyDielectricloss?

4

Chapter

DIELECTRICMATERIALS

Introduction

The material which store electrical energy are known as dielectricmaterial ,all dielectricmaterialare essentially insulatingmaterial .alldielectric are insulator but all insulators are not dielectric .Thematerialswhich are capableof retarding theflow of electricity orheatthrough them are known as dielectric or insulators. The safe handling of heat and electricity is almost impossible without use of an insulator. The material when used to prevent the loss of electrical energy and provides a safety in its operationis named as Electrical InsulatingMaterial. The properties which aretaken intoconsiderationforan insulatorarethe operatingtemperatureandbreakdown voltage.Howeverwhen itis usedtostore electricalcharge,itis known as DielectricMaterial.

The electrical conductivity of Dielectricmaterial isquitelowandthe bandgapenergy ismore than 3eV.Thisis thereason why thecurrentcannotflowthroughthem.Thecapacityofa capacitorcan beincreasedby inserting with adielectricmaterial,whichwasdiscoveredby Michael Faraday.

DielectricParameters

Theknowledgeofdielectricparameterishighlyessentialtochoosethespecificpurpose dielectric foruse.Those are Dielectricconstant,Dipolemoment,Polarization andPolari ability.

Dielectricconstant:

The proportionality constant in the relationbetween the electricflux density (D) and the electricfield intensity (E) is known as permittivity (ε) or dielectric constant. If the medium to which the electricfieldisappliedisafreespace(orvacuum),theproportionalityconstantofvacuumisε_0 of value 8.854 × 10^{-12} farad. meter.

DipoleMoment:

Two charges (Q+andQ-)of equalmagnitudebut of oppositepolarity,separatedwith distance d, constitutes a dipolemoment, given as:

$$p = Qd$$

pisthedipolemomentincoulomb-meter.

Dipolemoment is avectorpointingfrom thenegative chargeto the positivecharge and its unitis Debye (1 Debye = 3.33 × 10^{30} coulomb-metre)

Polarization:

ThedipolemomentperunitvolumeiscalledthepolarizationP.

Polarizability:

Theapplicationofan electricfieldtoadielectricmaterialcausesadisplacementofelectric chargesgiving rise to the creation orreorientation of thedipolesin thematerial.Theaverage dipole moment 'p' of an elementary particle may be assumed to be proportional to electric field strength E, that acts on the particle so that; The proportionality factor α is called polarizability, measures the average dipole moment per unit field strength. The unit of the polarizability is farad.meter^2.

MechanismofPolarization

The centre of gravity of positive charges and negative charges coincide in neutral atoms and symmetric molecules. When an electric field is applied to it, causesrelativedisplacementof charges, leading to the creation of dipoles andhencepolarizationtakes place.Un-symmetric arrangement of atom in amolecule results inadipole evenin the absenceofan externalfield and in those cases the applied electric field tends to orient the dipole moments parallel to the field direction. The mechanism for forming the dipoles are categorized as

- ElectronicorInducedpolarization,
- Ionicpolarization,
- Orientationpolarization,
- InterfacialorSpacechargePolarization.

DielectricLoss

The dielectric material separating the two electrodes or conductors is stressed when subject to a potential. When the potential is reversed, the stress also reversed. This change of stress involves molecularly arrangement within the dielectric.This involvesthe energy losswitheach reversal. This is becausethemoleculeshavetoovercomeacertainamountofinternalfrictioninthe process of alignment.The energy expandedin theprocessis releasedasheatinthedielectric. The loss appearing in the form of heat due to reversal of electric stresses, compelling molecular arrangement is known as dielectric loss.

When a dielectric material is subjected to an ac voltage, the leakage current I does not lead the appliedvoltageEbyexactly90^o asshowninvectordiagramthephaseangleφisalwaysless than 90^0.Thedielectricloss can becalculatedasfollows: Figure 4.1plotofE againstI_c

$$P = EI\cos\phi$$

$$\therefore P = E\frac{I_c}{\cos\delta}.\cos(90^0 - \delta) = E\frac{I_c}{\cos\delta}.\sin\delta = EI_c\tan\delta = E.\frac{E}{X_c}\tan\delta$$

Where $\phi = 90^0 - \delta$ and $I = \frac{I_c}{\cos\delta}$

Hence $P = E^2\, 2\pi fc.\tan\delta$

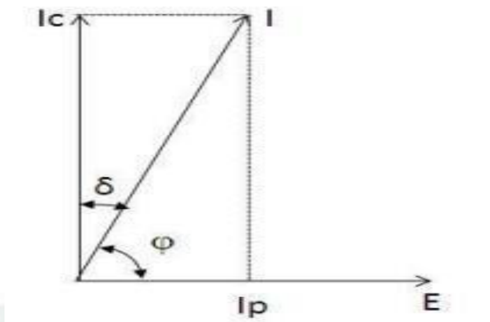


Figure4.1Plotof EagainstI$_c$

δ is the complement angle to φ and is called dielectric loss angle.tanδ is the measure of dielectric loss known as dissipation factor.

FactorsAffectingDielectricLoss

As observed from the equation of dielectric loss, the loss depends on the frequency and square of appliedvoltage. Dielectric loss increaseswith thepresenceof humidity andtemperaturerise**.**

ElectricalconductivityofDielectricandtheirBreakdown

Thedielectricmaterialisusedinelectricalandelectroniccircuitsasinsulatorsandasamedium in capacitors. When the applied electric field is increased, the potential difference across it also increases.A limitis reachedwhen thedielectricceases toworkasaninsulatorandaspark occurs. This limiting value of the voltage is known as Breakdown Voltage, which measures the strength of dielectric.

ConductionofGaseousDielectric

Airis thecommon gaseous dielectric.CosmicraysandUltravioletrayscausethenatural ionization in air. Since the opposite charges are equal, natural recombination takesplace continuously to check further ionization of whole air.

The free charges do not go for recombination if the medium is within an Electric field. Due to application of the electricfield,free chargesmove to their respective potential plates, causingaflowof currentknownas leakagecurrent.Themagnitudeofcurrentisdependentuponthe applied voltage. With the increase in voltage the directed flow of electrons and ions increases as comparedto randommotion in lowvoltage.If theappliedvoltageisfurtherincreased,theenergy of freecharges becomes sufficienttoforceoutelectrons evenfromneutralatom.Eachfree electron moves at a greatvelocity, collides with otherneutral atoms andknocksout free electron outofthem.This process increases ingeometricprogression.Theleakagecurrentincreases sharply in result to cause the breakdown of dielectric. The corresponding voltage is known as Breakdown voltage**.**

ConductionofLiquidDielectric

The liquid dielectric along with impurities of solid particle has more ability to conduct. The impurities get electrically charged and act as a current carrier. The fibrous impurities make the alignment of ions in a straight path for which the conductivity in liquid gets faster. In an uncontaminated liquid dielectric, such ion bridge cannot be formed. The breakdown of an uncontaminated liquid dielectric takes place dueto theionization of gasespresentin theliquid.The applied voltage ionizes the gas in liquid and the electric fieldintensity increases. It causesfurther ionization and ultimately the breakdown of dielectric takes place.

ConductionofSolidDielectric

Electrical conductivity of solid dielectrics may be electronic, ionic or both.In electronics current flow theflowof currentisdue to themovementof electronstowardsthe positive electrodes, while ionic current flow is due to the movement of positively charged ions towards the negative electrode. The impurities alsoplay the roleof conductivity in the dielectric.At low temperatures, theconductivityofsoliddielectricis duetotheimpuritiesonly.Athighertemperaturethe leakage current dependsupon the contribution offree ionsof the base dielectric. Breakdown ofsolid dielectrics may be electro-thermal or electrical. The heatproduceddueto dielectriclosscauseselectrothermalbreakdown andineffectdestructionof dielectric takesplace. If the dielectric is not able to radiate away the generated heat caused by dielectric loss and the applied voltage is retained for a long period thematerial gets melted. The electrodes get short circuited. Solid dielectric is not recoverable afterits break down likeliquidorgaseous dielectrics.

Table4.1Someofthedielectricmaterialandtheirrelativepermittivity

Sl.No	Dielectricmaterial	Relativepermittivity
1	Air	1.0
2	Bakelite	5to6
3	Glass	5to8
4	Mica	3to8
5	Paper	2to 2.5
6	Porcelain	4to7
7	Transformeroil	2.0

4.10ApplicationofDielectric

Themostcommonapplicationof dielectricisasacapacitortostoreenergy.

Capacitorare classifiedaccording to the dielectricusedin theremanufacturertheycanbe broadly classified as following categories

- Capacitorusingvacuumasdielectric
- Capacitorusingmineraloilasdielectric
- Capacitorusingcombinationsolid-liquiddielectric
- Capacitorwithonlysoliddielectric

MODELQUESTIONS
1. Whatdoyoumeanbydipolemoment?

5

Chapter

MAGNETICMATERIALS

Introduction

Thematerial which can bemagnetizedandare attracted by magnetiscalledasamagnetic material. Magnetic material have twomagnetic poles named as a south pole andnorth pole .like poles are repelwith each otherandunlike poles are attractedwith eachother.Magneticpole always in pair. There isno isolated single pole .if barmagnet is broken in to two parts .two new poles is formed.

Materials in which a state of magnetization can be induced are called magnetic materials when magnetized such materials create a magnetic field in the surrounding space. The property of a material by virtueof which it allowsitself to bemagnetized iscalledpermeability. Magnetsare two types’naturalmagnets and artificialmagnets .naturalmagnetsarecomefromminewhich are comparatively weak. Artificial magnets are made from iron, nickel, cobalt, steeloralloymaterial.

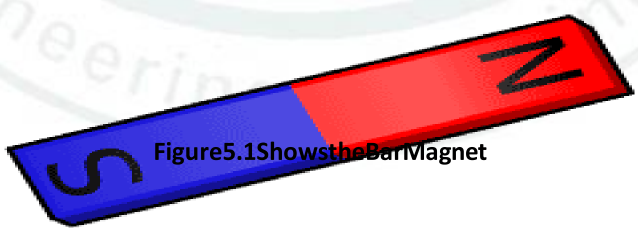


Figure5.1ShowstheBarMagnet

5.2 TermsarerelatedtoMagneticCircuit

Magneticflux:

Thetotalnooflinesofforceinamagneticfieldisknownasmagneticflux.Itsunitiswebers.

B = Flux / Area

WhereB-Fluxdensity

1Weber=10^8lines

Magneticfluxdensity:

μ = B /

HwhereB -Flux density

H-Magnetizingforce B

α H

μ=B/H

Permeability:

Permeability is amaterialproperty thatdescribes theeasewithwhichamagneticfluxis established in the component. It is the ratio of the magnetic flux density to themagnetic intensityand, therefore, represented by the following equation:

$$\mu = \frac{B}{H}$$

Itis clearthat this equation describes theslopeof thecurveat any pointon thehysteresisloop. The permeability value given in papers and reference materials isusuallythemaximumpermeability orthemaximum relativepermeability.Themaximumpermeabilityisthepoint where the slope of the B/H curve forun magnetizedmaterial isthe greatest. Thispoint isoften taken as the pointwhere astraightline from theorigin is tangent to the B/Hcurve.

The relative permeability $\mu_r$is arrived at by taking the ratio of the material's permeability μto the permeability in free space (air) μ_o.

5.3 ClassificationofMagneticMaterials

Magneticmaterialsclassifiedas:

1. **DiamagneticMaterial:**
   - Thematerialswhicharerepelled bya magnetareknownasdiamagnetic materials.
   - Examples of diamagneticmaterials areZinc, Mercury, lead,Sulphur, Copper, and Silver.
   - Theirpermeabilityisslightly lessthanone.
   - They areslightlymagnetizedwhenplacedinastrongmagneticfieldandactin the direction opposite to that of applied magneticfield.
   - Theyarerepelledbymagnet
   - Theydonotretainthemagneticpropertieswhenexternalfieldisremoved.

2. **ParamagneticMaterials:**
   - Thematerialswhich arenotstrongly attractedbyamagnetareknown as paramagnetic materials.
   - Examplesofparamagnetic materialsare Aluminum,Tin, Platinum, Magnesium, Manganese, etc.
   - Theirrelativepermeability'sissmallbutpositive.
   - Suchmaterialsareslightlymagnetizedwhenplacedinastrongmagneticfield.
   - Theydonotretainthemagneticpropertieswhenexternalfieldisremoved.
   - Theyareweaklyattractedbymagnet.

3. **Ferro-MagneticMaterials**
   - Thematerials which are stronglyattracted by a magnet are known asferro-magnetic materials.
   - Theirpermeabilityisveryhigh.
   - Examplesofferro-magneticmaterial.Iron,Nickel,Cobalt,etc.

5.4 MagnetizationCurve

The curvedrawn givingrelationshipbetweeninductiondensity“B”andmagnetizingforce“H” is known as magnetization curve or B ~ H curve.

This figure shows the general shape of B ~ H curve of magnetic material. In general it has four distinctregionsoa,ab,bcandtheregionsbeyondc.During theregion oatheincreaseinflux densityisverysmall,inregionabthefluxdensityBincreasesalmostlinearlywiththe magnetizingforceH,inregionbctheincreaseinfluxdensityisagainsmallandinregion beyond point c, the flux density “B” is almost constant. The flat part of the magnetization curve corresponds to magnetic saturation of the material.

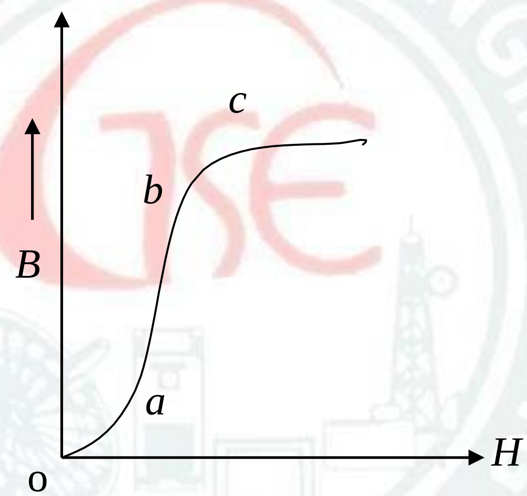


Figure5.2Magnetizationcurve

Hysteresis loss: In mostcases hysteresis is a liability as it causesdissipation of heat,wasteof energyandhumming due tochangeinpolarity androtationofelementmagnetsin thematerial. If a magnetic substance is magnetized in a strong magnetic field it retains someportionofmagnetismafterthemagneticforceiswithdraw.Thephenomenonoflaggingofmagnetization orinduction flux density behindthemagnetizing forceisknownasmagnetichysteresis.The losses due to hysteresis are known ashysteresis loss. Hysteresis loss depends upon themaximum flux density “Bm” and frequency of variation of flux is expressed as:

Hysteresisloss=η**1.6fv**B_m**1.6J/SorWatt**

η = isaconstant. It isknownas Steinmetzhysteresis coefficient

Where f = frequency of reversal of magnetization

B_m=Maximumfluxdensity,v=Volumeofmagneticmaterial

Eddy current loss: When magnetic material is placed in alternating magnetic field, it cuts the magnetic flux. According to laws of electromagnetic induction an EMF is induced.This EMF causing current isknown asEddy current. The power loss due to the flow of thiscurrent isknown as Eddycurrent loss

Eddycurrent lossisproportional to the square of the frequencyand the square of the thicknessof the material and is inversely proportional to the resistivity of the material. The expression for Eddy current loss is

Eddy current loss = $K B_m^2 f^2 t^2 v^2$ Watt

WhereB_m=Maximumfluxdensity, K= Constant

f=Frequencyofmagneticreversal,t=Thicknessoflamination,
v=Volumeofmagneticmaterial

Curie point: A critical temperature above which the Ferro-magnetic material loses their magnetic properties is known as Curie point.

5.5 TheHysteresisLoopandMagneticProperties

Agreatdealofinformationcanbelearnedaboutthemagneticpropertiesofamaterialby studying its **hysteresis** loop.Ahysteresis loopshows therelationshipbetweentheinduced magnetic flux density **B** and the magnetizing force **H.** It is often referred to as the B-H loop. An example hysteresis loop is shown below.

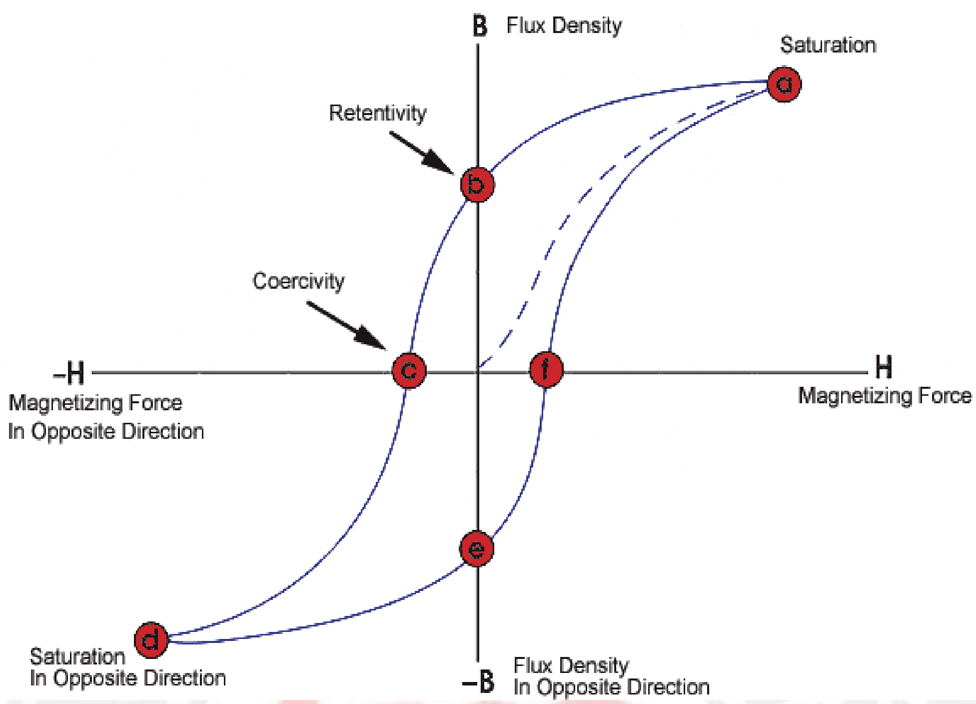


Figure5.3HysteresisLoop

The loop is generated by measuring the magnetic flux **B** of a ferromagnetic material while the magnetizing force **H** is changed. A ferromagnetic material that has neverbeenpreviously magnetized orhasbeen thoroughly demagnetizedwillfollowthe dashedline as**H** isincreased. As thelinedemonstrates,thegreatertheamountofcurrentapplied**(H+)**,thestrongerthe magneticfieldinthecomponent**(B+)**.Atpoint"a"almostallofthemagneticdomainsare aligned and an additional increase in the magnetizing force will produce very little increase in magneticflux.Thematerialhas reached the pointof **magnetic saturation**.When **H** is reduced backdowntozero,thecurvewillmovefrom point"a"topoint"b."Atthispoint,itcanbeseen thatsomemagneticflux density remains in thematerial even though themagnetizingforceis zero. This is referred to as the point of **retentivity** on the graph and indicates the level of residual magnetism in thematerial.Some ofthemagnetic domainsremainalignedbutsomehavelost their alignment. As the magnetizing force is reversed, the curve moves to point "c", where the magneticflux densityhas been reducedtozero.Thisiscalledthepointof**coercivity**on the curve.Thereversedmagnetizingforcehasflippedenoughofthedomainssothatthenet magnetic flux density within the material is zero. The H-field required to remove the residual magnetismfrom thematerial,is called the **coercive force** or **coercivity** of thematerial.

As the magnetizing force is increased in the negative direction, the material will again become magnetically saturated but in theopposite direction (point"d"). Reducing**H** to zero bringsthecurve to point "e." It will have a level of residual magnetism equal to that achieved in the other direction.Increasing**H** backin thepositive direction will return**B** to zero.Notice that thecurve didnotreturntotheoriginofthegraphbecausesomeH-fieldis requiredtoremovetheresidual magnetism.Thecurvewilltakeadifferentpathfrompoint"f"backthesaturationpointwhereit withcompletetheloop.

5.6 MagnetizationsorB-HCurve

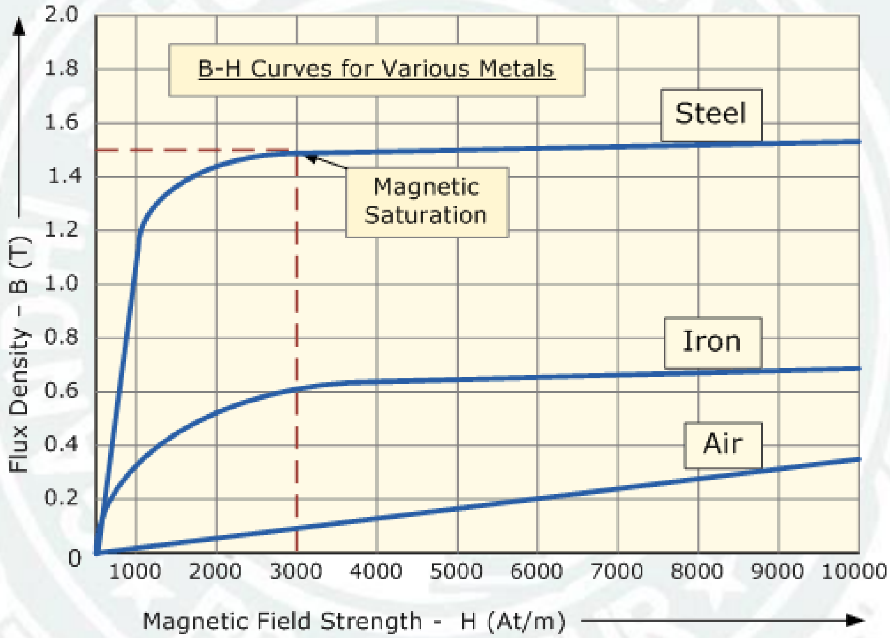


Figure5.4B-HCurves

Ferromagneticmaterialsalsoshowa"**hysteresis"effect**,wheredecreasingtheappliedmagnetic field,or*H*,doesn'tproducethereverseeffectofincreasingthefield.

The shape of the hysteresis loop tells a great deal about the material being magnetized.The hysteresis curves of two different materials are shown in the graphs below. "Hard" magnetic materials:H_c(coercivity)ishigh;areaoftheloopislarge,usedforpermanentmagnets."Soft" magnetic materials:$H_c$issmall; area ofloopis small,usedfor transformer cores&electromagnets.

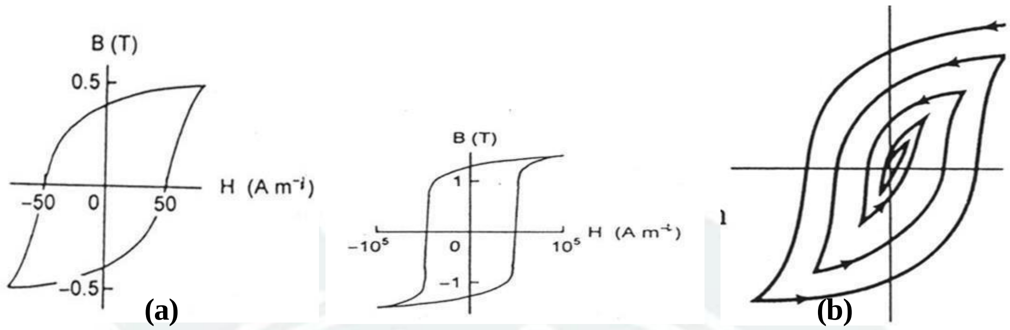


Figure5.5(a)Softmagneticmaterial;(b)Hardmagneticmaterial

Material can bedemagnetized by striking orheating it,orgoround thehysteresis loop,gradually reducing its size. *"Degaussing"*

SoftMagneticMaterials

Materials which retain their magnetism and are difficult to demagnetize are called hard magnetic materials.Thesematerialsretaintheirmagnetismevenaftertheremovaloftheapplied magneticfield.Softmagneticmaterialsareeasytomagnetizeanddemagnetize.These materials are used formaking temporarymagnets. Materialsthatcan bemagnetized,which arealso the ones thatarestrongly attractedto amagnet,arecalled**ferromagnetic.** Theseinclude iron,nickel,cobalt,somealloys of rare-earthmetals,andsomenaturallyoccurringminerals. **Hard** magnets, also referred to as permanent magnets, are **magnetic materials** that retain their magnetism after being magnetized such as lodestone.

Softmagneticmaterialsareusedfortheconstructionofcoresforelectricmachines, transformers, electromagnets, reactors, relays. In order to keeps the magnetizing current and iron losses low using a low flux density.

PureIron:

Pure iron is a ferrous material with extra-low carbon content. Examples Low-carbonsteel, electrolytic iron.The resistivity of pureiron isvery lowby virtueof which itgives rise to large eddycurrentlosseswhenoperatedathighfluxdensitiesinalternatingmagneticfields.Pureiron is used in many kinds of electrical apparatus and instruments as magnetic material core for electromagnets, components for relay electrical instruments.

IronSiliconAlloys:

Thechiefalloyingconstituentissiliconwhichisaddedtoironinamountsfromabout0.5to5% by weight. Iron-Silicon alloy usually known as Silicon steel. Silicon steel generally used in transformers, electrical rotating machines, reactors, electro magnets and relays. Silicon sharply increases the electrical resistivity of iron thus decreasing the iron losses due to eddy currents. It increases the permeability at low and moderate flux densities but decreases it at high densities. Addition of silicon to iron reduces the hysteresis loss. The magnetostriction effect is reduced. Addition of silicon is valuable because it facilitates the steelmaking process.Alloyingoflow carbon steel with siliconincreasesthetensilestrength;it reducesductivity making steel brittle.This makes silicon alloyedsteel difficult to punch and shear.

GrainOrientedSheetSteel:

As theferromagneticmaterialshaveacrystalstructure.Soeverycrystalofferromagnetic substance has a particular direction along which it offers high permeability. So it most easily magnetized. Such axes along which the crystals have high permeability and are move easily magnetized are called as easy or soft direction. Along any axis other than the easy direction, the crystalhas low permeability andistherefore more difficult tomagnetize. Such axes alongwhich the crystal has low permeability are called as hard direction. For easy magnetization the crystal directions of electrical sheet should be so oriented that their axes are parallel to thedirectionin which the external magneticfieldis applied. Thisisachievedin practice by carefully controllingtherollingandannealingofsiliconironsheets.Thedirectionofeasymagnetizationthenliesin the direction in which thesteel is rolled in themill.Sheetsteel which hasbeen rolledsuch as to giveeasy direction to all its crystals is called „textured‟orgrain orientedsteel.

MagneticAnisotropy:

The directionaldependence ofmagnetic propertyunderheadinggrainorientedsheetsteelis known asmagnetic anisotropy.It isclearthat in bulkmagnet agreatimprovement will result if the individual preferred axes are aligned parallel and along the axis of magnetization.

Annealing:

The magnetic properties of Ferro-magnetic materials are affected by strain due to mechanical working like punching,milling,grinding,machineries,etc.Themagneticpropertiesincluding the correct crystal direction by heat treatment. Since mechanical stressing disturbs the crystal orientation,it is essential to perform thattreatmentonceagainafterallmechanicaloperations have been completed.

Soft Ferrites:

Ceramicmagnetcalledas ferromagnetic ceramic andferrites. Ceramicmagnetismadeof an iron oxide,Fe_2O_3withoneormoredivalentoxidessuchasNiO,MnOorZnO.Thesemagnets have a square hysteresisloop and high resistance to demagnetization. The great advantagesof ferrites are theirhigh resistivity.Theirresistivity's areas109Ohm-cm.Ferritesarecarefully made by mixing power oxides compacting and sintering at high temperatures. High frequency transformersintelevisionandfrequencymodulatedreceiversarealmostalwaysmadewith ferrite core.

HardMagneticMaterials

Hard magnets, also referred to as permanent magnets, are magnetic materials that retain their magnetism after being magnetized.

Hard-magnetic materials are used for making permanent magnets. The properties ofmaterial required of making permanent magnets are high saturation values, high coercive force and high residual magnetism.

Thehard-magneticmaterials arecarbonsteel,tungstensteel,cobaltsteel,alnico,hardferrites.

CarbonSteel,TungstenSteel,CobaltSteel:

As thesoft-magneticmaterials havenarrowhysteresis loops,sowhencarbonisaddedina materialitshysteresisloopareais increased.Althoughitischeap,magnetsaremadefrom carbon steel loss theirmagnetic propertiesvery fast underinfluence ofknocksand vibrations. Whenmaterials liketungsten,chromium orcobaltareaddedtocarbonsteel,itsmagnetic properties are improved.

Alnico:

It is known as Aluminum-nickel-iron-cobalt.Alnicoiscommercially themostimportantof the hard magnetic materials. Large magnets are made by special casting techniques and small one by powdermetallurgy.Ascobaltsteelischeapersofarthesereasonpermanentmagnetsaremost commonlymadeofAlnico.

HardFerrites:

Hardmagneticferrites like $BaO(Fe_2O_3)_6$ are usedforthemanufactureof lightweightpermanent magnets due to their low specific weight

MODELQUESTIONS
1. Whatishardferrite? 2. WhatisParamagneticmaterial? 3. Whatisdiamagneticmaterial?

6

Chapter

MATERIALSFORSPECIAL PURPOSES

6.1 Introduction

Somematerialsusedforspecialpurposessuchasfuses,solder,bimetal,storagebatteryplates.

Thosematerialsusedforspecialpurposesareinstructuralmaterialsorprotectivematerials.In electricalengineeringspecialpurposeofmaterialis

1. Structural Material
2. Protective Material
3. ThermocoupleMaterial
4. Bi Metal
5. SolderingMaterial
6. FusingMaterial

6.1.1StructuralMaterials

Castiron,steel,timber,reinforcedconcretearecommonmaterialsforthispurpose.Castironis usedasmaterialsfortheframesofsmallandmediumsizedelectricalmachines.Steelisusedin fabricated framesinlargeelectricalmachine,tanksintransformers,fabricationoftransmission towers. Timber and reinforced concrete are used for poles in OH lines.

ProtectiveMaterials

Lead: Leadissoft,heavyandbluishgreymetal.Itishighlyresistanttomuchchemicalaction, but it can corrode by nitric acid, acetic acid, line and rotten organic substance. The electrical conductivity is7.8%of copper.Leadisused in storagebatteriesandsheathingof cables. Pure lead cable sheathing is liable to fail in service due to formation of cracks formed becauseof vibration. Lead alloys with tin and zinc and forms alloys which are used for solders and bearing metals.

Steel Tapes, Wires and Strips: Steel tapes, wires and strips are used as protective materials for mining cables, underground cable, and weather proof cables.

ThermocoupleMaterials

- Thermo couplematerial are used formeasurementof temperaturedepending on the range of temperature to be measured
- Proper material are to be selected for thermo couple thermo couple is a device used extensivelyformeasuringtemperatureathermocoupleconsistoftwometaljoin together to fromtwo junction 1)cold junction 2)hot junction
- When two wires of different metals are joined together an EMF exists across the junction. This EMF is directly proportional to the temperature ofthe junction.
- WhenonetriestomeasurethisEMFmorejunctionsaretobemadewhichwillgiverise to EMFs.When all thejunctionsare at thesame temperature,the resultantEMFwill not be zero. This resultant EMFisproportional to the temperature difference of the junctionsand is known as thermoelectric EMF.
- Thermo couples are made of different materials such that copper / constantan, iron / constantan,platinum/platinumrhodium.Thermocouplescanbeusedforthe measurement of temperature.

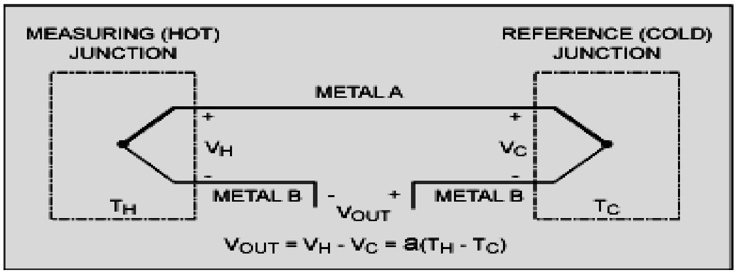


Figure6.1Theloopvoltagegeneratedbythetemperaturedifferencebetweentwojunction

Bimetals

- Bimetals is basedon the theory thatexpandson heating and contracton cooling. It works on theprincipleofheating effect of electric current .thebimetalheateddirectlyor indirectly 'a bimetal is made of two metallic strips. Bimetallic strips are used in electrical apparatus and device as relay and regulator for example in order to maintain a constant temperature in aheaterasimplebimetallicregulatormay beusedbimetal relay can be used for over load protection of electricalmotor or any electriccircuit.ifthecurrent exceeds certainvalue,thestripwillheatedenough to bendandbreak thecircuitso in order tomaintain constant temperaturein electricheater,oven,furnaceetcsimple bimetallicregulator is usedmany bimetallicdeviceare adjustablefor aparticularcurrent.
- A bimetal ismadeof twometallicstripsof unlikemetal alloyswith different coefficient ofthermalexpansion.Atacertaintemperaturethestripwillbendandactuateaswitchor a lever of a switch. The bimetal can beheated directly or indirectly. Whenheated the element bends so that the metal with the greatercoefficient of expansion is on the outside they are formed while that with smaller coefficient ison theinside. Bimetallic stripsare used in electrical apparatus andsuch as relays and regulators.

SolderingMaterials

- Solderisanalloyoftwopiecesofmetalsoflowmeltingpointwhichisusedtojointwo ormorepiecesofmetals.Theprocessofjoiningthepiecesofmetalisknownas soldering
- Apieceofsolderwireisplacedoverthejointandheatedwithpropertemperature
- It is necessary toheat the jointup to a proper temperature .if it isnotproperlyheated, proper soldering cannot be done and if joint is overheated themetal is weakened.

- Solderinelectricalpurposedividedintotwotypessoftsolderandhardsolder
- An alloy of two or more metals of low melting point used for base metals is known as soldering.Thealloyusedforjoining themetalsis knownassolder.Thesolderis composed of 50% lead and 50% tin. For proper soldering flux is to be used. In soldering processtheapplicationoffluxservestoremovesoxidesfromthesurfacetobesoldered.

  They deoxidize themetals at thetimethesolderingelementisadded.Soldersaretwo types such as soft solders and hardsolders soft solders are composed of lead and tin in variousproportions.Hardsoldersmaybeanysolderwithameltingpointabovethatof leadtinsolders.

SoftSolder

- Soft solders are composed ofleadand tin It's
- melting point is lower than 4000c
- Theseareusedforsolderingcopper,bronze,brassandothersuchmetals.theseareused inelectronicdevices

HardSolder

- Hard solderisanalloy of copper and zinc It's
- melting point is higher than 4000c
- Theseareusedforsolderingiron,gold,steel,silveretc
- Theseareusedformakingpermanentconnection

Figure6.2Solderingironswithsolderwireandfluxstock

FusingMaterial

A fuse is a protective device, which consists of athin wire orstrip. This wire is placed with the circuit which heave to protect,so that the circuit.Current flowsthroughit.When thiscurrentis too high the temperature of the wire orstripwill increase till the wireor stripmelts. So breaking the circuit and interrupting the power supply.

A fuse is asafety device consisting of astrip ofwire thatmeltsandbreaksanElectric circuit if the current exceeds the safe value.

Characteristicsofafuseare:

- Itshouldhave lowmeltingpoint.
- Itshouldhavehighconductivity(orlowresistivity).
- Itshouldbeeconomical.
- Itdoesnotgetoxidizedandisoxideisunstable.
- Theconductivityofsilverisnotdeterioratedwithoxidation.
- Highconductivity.

Fuse elements materials: The materials commonly used for fuse elements are tin, lead, silver, copper,zinc,aluminium,andalloysofleadandtin.An alloyofleadandtin (lead37%andtin 63%) is used forfuses with acurrentrating below15A For current exceeding 15A copperwire fuses are employed. The present trendisto use silveras fuse element material despite itshighercost owing to the following advantages:

1. **LowVoltageFuses**

   Semi-EnclosedRewireAbleFuses

   ItisalsocalledasKit-Katfuse.Itmainlyconsistsoftwoparts:

   a) Base

   b) CarrierBaseismadeofporcelainwhichholdsthewires.

Base is made of porcelain which holds the wires.The fuse element is located inside the carrier that is also made of porcelain. Fuse carrier can be removing without ariskof electrical shock. When there is a fault, the fuse element is blown out and the circuit is interrupted.Thefusecarrieris then takenoutand theblownoutwireisreplacedwith new one and re-inserted to base to restore supply.

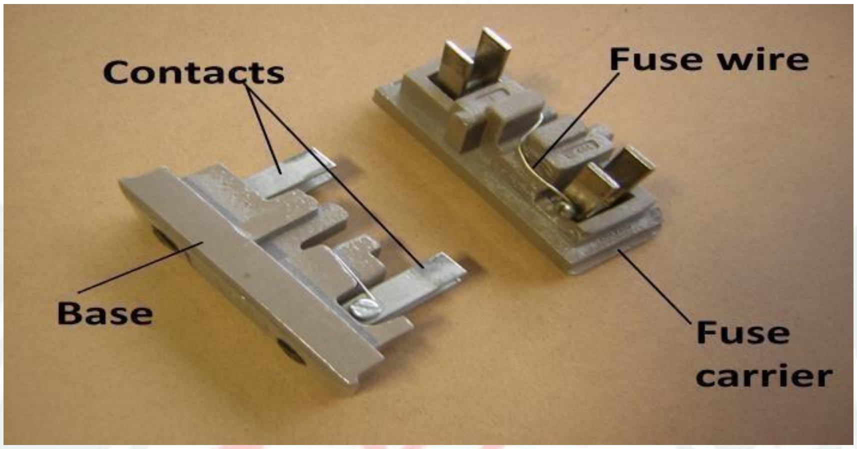


Figure6.3Semi-enclosedrewireablefuses

2. **High VoltageFuses**

Cartridge Type

Thistypeoffusesissimilaringeneralconstructiontolowvoltagecartridgetypeexcept somespecialdesignfeatures.Therearetwofuseelementsareincorporatedinparallel:

a) Lowresistancewire(silverwire)

b) Highresistancewire(tungstenwire)

When afault occurs,thelowresistanceelement is blown out andhighresistanceelement reducestheshort circuit currentandfinallybreaksthe circuit.Thesetypeoffusesare usedupto33kVwithbreakingcapacityofabout8700Aatthatvoltage.

Figure6.4CartridgeFuse

6.2 DehydratingMaterial–SilicaGel

It is in organicchemical,colloidalhighly absorbentsilicausedasade-humidifyingand dehydrating agent as a catalyst carrier. Calcium chloride and silica gel are used in dehydrating breathers to remove moisture from the air entering a transformer asit breathes. Nowsilica gel isused for breather of a transformer. Its main advantage is that when it becomessaturated with moistureitdoes notrestrictbreathing.Silicagelwhen dryisblueincolourandthecolour changes to pale pink as it becomes saturated with moisture.

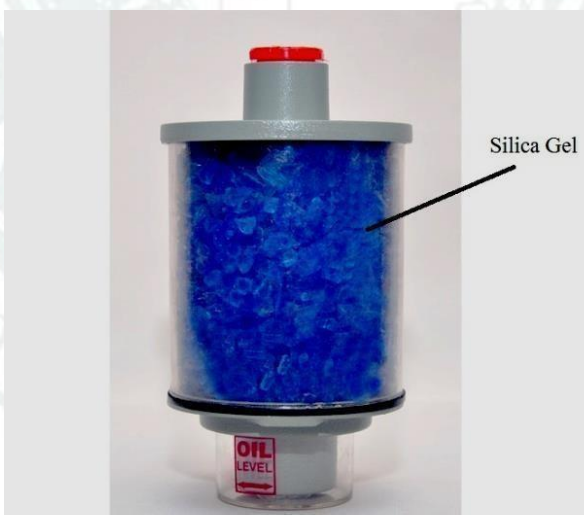


Figure6.5Silicagelbreatherintransformer

In transformers Silica gel portion is referred as Silica gel breather. It is usually connected to conservator tank through a breathing pipe. Whenever transformer is loaded i.e. near to full load, temperature of the Transformer oil get increased which leads to expansion of transformer oil means volume of oil get increased. Now when Volume of oil get increased air trapped above oil level in conservator tank comes out.

Now when transformer is lightly loaded transformer oil cools down which will leads to decrease in transformer oil volume. Which will leads to air from surroundings get enter above conservator oil level, now this air contains moisture which must be needed to removed otherwise it will leads to moisture getting mixed withoil. Ifthis moisture get mixed withoil thanthat will be veryharmful for transformer Insulation. To remove this moisture silica gel is used. Silica gelabsorbs this moisture and doesn't allow moisture getsenter into transformer.

As during this process air leaves and enters the transformer that is why this is knows as silica gel breather. Which means transformer is breathing.

Silica gel isblue incolor but whenit startsabsorbing moisture it starts get pink in color. There isnot defined life of silica gel, When 50% of silica gel turned into pink means there is need to change the silica gel.

MODELQUESTIONS	
1.	Whatisfuse?
2.	Whatissilicagel?
3.	Whatissoftsolder?
4.	Whatishardsolder?