NEHRU COLLEGE OF ENGINEERING AND RESEARCH CENTRE
(NAAC Accredited)
(Approved by AICTE, Affiliated to APJ Abdul Kalam Technological University, Kerala)

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

COURSE MATERIALS

EE206 MATERIAL SCIENCE

VISION OF THE INSTITUTION

To mould true citizens who are millennium leaders and catalysts of change through excellence in education.

MISSION OF THE INSTITUTION

NCERC is committed to transform itself into a center of excellence in Learning and Research in Engineering and Frontier Technology and to impart quality education to mould technically competent citizens with moral integrity, social commitment and ethical values.

We intend to facilitate our students to assimilate the latest technological know-how and to imbibe discipline, culture and spiritually, and to mould them in to technological giants, dedicated research scientists and intellectual leaders of the country who can spread the beams of light and happiness among the poor and the underprivileged.

COURSE OBJECTIVES

Course Name: EE206 MATERIAL SCIENCE YEAR of Study: SECOND YEAR

C206.1	Describe the characteristics of conducting and semiconducting materials.
C206.2	Classify magnetic materials and describe different laws related to them.
C206.3	Classify and describe different insulators and to explain the behavior of dielectrics in static and alternating fields
C206.4	Describe the mechanisms of breakdown in solids, liquids and gaseous
C206.5	Classify and describe solar energy materials and super conducting materials
C206.6	Gain knowledge in the modern techniques for material studies.

PROGRAM OUTCOMES (POs)

Engineering Graduates will be able to:

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design/development of solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

5. **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society**: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clearinstructions.
11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinaryenvironments.
12. **Life-long learning**: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technologicalchange.

CO-PO matrices of courses

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
C206.1	3	1	3	3	3	2	2	2	-	-	-	3
C206.2	3	1	3	3	3	2	2	2	-	-	-	3
C206.3	3	1	3	3	3	2	2	2	-	-	-	3
C206.4	3	1	3	3	3	2	2	2	-	-	-	3
C206.5	3	1	3	3	3	2	2	2	-	-	-	3
C206.6	3	1	3	3	3	2	2	2	-	-	2	3
C206	3	1	3	3	3	2	2	2	-	-	0.33	3

CO AND PSO MAPING

PSO

1. Apply Science, Engineering, Mathematics through differential and Integral Calculus, Complex Variables to solve Electrical Engineering Problems.

2. Demonstrate proficiency in the use of software and hardware to be required to practice electrical engineering profession.

3. Able to apply the knowledge of Ethical and Management principles required to work in

CO/PSO	PSO1	PSO2	PSO3
C206.1	3	3	1
C206.2	3	3	1
C206.3	3	3	1
C206.4	3	3	1
C206.5	3	3	1
C206.6	3	3	1
C206	3	3	1

Course No.	Course Name	L-T-P -Credits	Year of Introduction
EE206	MATERIAL SCIENCE	3-0-0-3	2016

Prerequisite : Nil

Course Objectives

To impart knowledge in the field of material science and their applications in electrical engineering

Syllabus:

Conducting materials- properties-applications- Semi conductor materials- properties-applications- Magnetic materials-classification-alloys of iron-ferrites-Dielectric materials-polarization-solid, liquid and gaseous insulators-Dielectric breakdown-superconductors-solar energy materials-Spectroscopy-micropscopy-magnetic resonance-nanomaterials

Expected Outcome:

After the completion of the course student will be able to:

1. Describe the characteristics of conducting and semiconducting materials
2. Classify magnetic materials and describe different laws related to them
3. Classify and describe different insulators and to explain the behaviour of dielectrics in static and alternating fields
4. Describe the mechanisms of breakdown in solids, liquids and gases
5. Classify and describe Solar energy materials and superconducting materials
6. Gain knowledge in the modern techniques for material studies

Text Book:

1. Dekker A.J : Electrical Engineering Materials, Prentice Hall of India
2. G K Mithal : Electrical Engg Material Science. Khanna Publishers.

References:

1. Tareev, Electrical Engineerin Materials, Mir Publications
2. Meinal A.B and Meinal M. P., Applied Solar Energy – An Introduction, Addisos Wesley
3. Nasser E., *Fundamentals of Gaseous Ionization and Plasma Electronics*, Wiley Series in Plasma Physics, 1971
4. Naidu M. S. and V. Kamaraju, *High Voltage Engineering*, Tata McGraw Hill, 2004
5. Indulkar O.S &Thiruvegadam S., An Introduction to electrical Engineering Materials, S. Chand
6. Agnihotri O. P and Gupta B. K, Solar selective Surface, John wiley
7. Seth. S.P and Gupta P. V, A Course in Electrical Engineering Materials, Dhanpathrai

Course Plan

Module	Contents	Hours	Sem.ExamMarks
I	Conducting Materials: Conductivity- dependence on temperature and composition – Materials for electrical applications such as resistance, machines, solders etc. Semiconductor Materials: Concept, materials and properties-– Basic ideas of Compound semiconductors, amorphous and organic semiconductors- applications. Dielectrics: Introduction to Dielectric polarization and classification –Clausius Mosotti relation- Behavior of dielectric in static and alternating fields	8	15%
II	Insulating materials and classification- properties- Common insulating materials used in electrical apparatus-Inorganic,	6	15%

	organic, liquid and gaseous insulators- capacitor materials- Electro-negative gases- properties and application of SF6 gas and its mixtures with nitrogen Ferro electricity.		
FIRST INTERNAL EXAMINATION			
III	Dielectric Breakdown: Mechanism of breakdown in gases, liquids and solids –basic theories including Townsend's criterion, Streamer mechanism, suspended particle theory, intrinsic breakdown, electro-mechanical breakdown- Factors influencing Ageing of insulators- Application of vacuum insulation- Breakdown in high vacuum-Basics of treatment and testing of transformer oil .	7	15%
IV	Magnetic Materials: Origin of permanent magnetic dipoles- Classification of magnetic materials -Curie-Weiss law- Properties and application of iron, alloys of iron- Hard and soft magnetic materials– Ferrites- Magnetic materials used in electrical machines, instruments and relays-	7	15%
SECOND INTERNAL EXAMINATION			
V	Superconductor Materials:-Basic Concept- types- characteristics-applications Solar Energy Materials: Photo thermal conversion- Solar selective coatings for enhanced solar thermal energy collection –Photovoltaic conversion – Solar cells -Silicon, Cadmium sulphide and Gallium arsenic – Organic solar cells.	7	20%
VI	Modern Techniques for materials studies: Optical microscopy – Electron microscopy – Photo electron spectroscopy – Atomic absorption spectroscopy – Introduction to Biomaterials and Nanomaterials	7	20%
END SEMESTER EXAM			

QUESTION PAPER PATTERN (End semester exam)

Part A: 8 questions.
One question from each module of Module I - IV; and two each from Module V & VI. Student has to answer all questions. (8 x5)=40
Part B: 3 questions uniformly covering modules I&II.
Student has to answer any 2 questions: (2 x 10) =20

Part C: 3 questions uniformly covering modules III&IV.
Student has to answer any 2 questions: (2 x 10) =20

Part D: 3 questions uniformly covering modules V&VI.
Student has to answer any 2 questions: (2 x 10) =20
Note: Each question can have maximum of 4 sub questions, if needed.

EE206-MATERIAL SCIENCE

MODULE-I

Prepared By
Rajkumar G
Assistant Professor, EEE Department
NCERC

Contents

- Conducting Materials: Conductivity- dependence on temperature and composition – Materials for electrical applications such as resistance, machines, solders etc.
- Semiconductor Materials: Concept, materials and properties-– Basic ideas of Compound semiconductors, amorphous and organic semiconductors- applications.
- Dielectrics: Introduction to Dielectric polarization and classification – Clausius Mosotti relation-Behavior of dielectric in static and alternating fields.

Conductor

Conductivity – Dependence On Temperature & Composition

→ The effect of high temperature decreases the conductivity o f a metal. The effect o f high temperature varies cubically at low temperature & linearly at high temperature.

→ Composition means forming alloys (example “ nichrome”) or adding impurities to pure metal.

→ Composition decreases the conductivity.

Classification of conducting material

Conducting materials are broadly classified in to two

(i) Low resistivity material (Silver, Copper, Gold, Aluminium, Zinc, Nickel, Cadmium, Iron, etc)

(ii) High resistivity material (Tungsten, Nichrome, carbon, Mangenese, Platinum,Constantan etc)

Properties of Low resistivity material

(i) Low resistance-temperature coefficient

This means that the change of resistance with change in temperature should be low. If resistance is increased with temperature, the power loss and voltage drop is increased. To avoid this situation ensure materials are low resistance-temperature coefficient.

(ii) High Melting Point:-

It should have ability to withstand high temperature for long time without melting.

(iii) No tendency for Oxidation:-

It should not have no tendency to oxidize at high temperature. If an oxide layer is formed on heating element, the amount of heat radiation is reduced.

(iv) It should have high mechanical strength so that if it is drawn into thin wires it may not break.

(v) Ductility:-

It can be drawn into any shape and size easily.

Properties of High resistivity material

(i) Low resistance-temperature coefficient:-

This means that the change of resistance with change in temperature should be low. If resistance is increased with temperature, the power loss and voltage drop is increased. To avoid this situation ensure materials are low resistance-temperature coefficient.

(ii) High Melting Point:-

It should have ability to withstand high temperature for long time without melting.

(iii) No tendency for Oxidation:-

It should not have no tendency to oxidize at high temperature. If an oxide layer is formed on heating element, the amount of heat radiation is reduced.

(iv) It should have high mechanical strength so that if it is drawn into thin wires it may not break.

(v) Ductility:-

It can be drawn into any shape and size easily.

Low Resistivity Materials

(i) **Copper :-** Copper is a crystalline, non-ferrous, diamagnetic , reddish colored metal.

Advantages:- → Highly conductive material, low cost & resistivity is (28 * 10^-9)

Properties:- → Due to high ductility (about 55%), Suitable for making thin wires.

→ Due to high melting point (1083˚C), suitable for use at high temperature.

→ High tensile strength (300-350MPa) provide more strength towards mechanical loads.

Applications:- → Annealed Copper is used as power cables, winding wires for electrical machines.

→ Hard drawn copper is suitable for overhead transmission lines, bus-bars etc.

(ii) **Aluminium :-** Aluminium is a crystalline, non-ferrous, paramagnetic , white colored metal.

Advantages:- → conductive is lower than copper (about 75% less) , light weight &low cost material.

Properties:- → Due to high ductility (about 50%), Suitable for making cables, strands &conductors

→ Due to low tensile strength (50-70 MPa), not suitable for making windings of electrical machines.

High Resistivity Materials

(i)Tungsten

- It is used in incandescent lamp as filament due to high melting point (3300°C).
- It has very high tensile strength in its thinnest form.
- It does not brittle at high temperature.

(ii) Nichrome

- It is an alloy of [Mn(1.5%), Ni(75-78%), Cr(20-23%)]
- It is used for making heating elements of electric heaters, electric ovens, room heaters, electric furnaces etc.
- It has good mechanical strength and desirable thermal properties

(iii) Manganin

It is an alloy of [Cu(86%), Mn(12%), Ni(2%)]

- It can easily drawn into thin wires
- It is used in making resistance boxes, resistors for precision instruments, shunts for electrical measuring instruments etc.

(iv) Constantan

- It is an alloy of [Cu(60%), Ni(40%)]
- It is used for making loading rheostats, starters for electrical motors, fieldwinding for generatorsetc.

Materials for Electrical Applications

- Carbon is used for making brushes of electrical machines.
- Brass is used for making slip rings of alternator.
- Lead- Tin mixture [37% lead – 63% Tin] is used for making fuses.
- Lead- Tin mixture [50% lead – 50% Tin] is used for making solders.

Semi conductor

Elemental Semiconductors

- In an elemental semiconductor, all atoms are of the same element

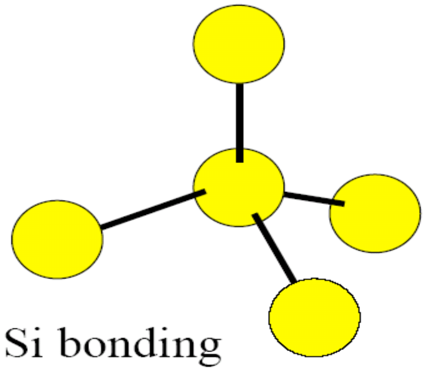
Eg: Ge, Si

Germanium

- It is a grey metallic looking material
- It is brittle and glass like in its mechanical properties
- It has an intrinsic resistivity of 47ohm cm
- This type of semiconductor material was used in many early devices from radar detection diodes to the first transistors.

- Ge Diodes show a higher reverse conductivity and temperature coefficient.
- Offers a better charge carrier mobility than silicon and is therefore used for some RF devices.
- Not as widely used these days as better semiconductor materials are available

Silicon



- Silicon has the diamond structure

- Silicon is the most widely used type of semiconductor material. Its major advantage is that it is easy to fabricate and provides good general electrical and mechanical properties.

- Another advantage is that when it is used for integrated circuits it forms high quality silicon oxide that is used for insulation layers between different active elements of the IC.

- Si has four valence electrons. Therefore, it can form covalent bonds with four of its nearest neighbors.

- When temperature goes up, electrons can become free to move about the Si lattice.

- Modern electronic devices are constructed with resistors, diodes, transistors, integrated circuits which are made by semiconductor materials.

- Silicon is resistant to very high temperature and current. The maximum operation temperature of silicon transistors is 150^{o}C while for example germanium transistor has up to 70^{o}C.

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- There are 2 types of mobile charge-carriers in Si:
    - Conduction electrons are negatively charged;
    - Holes are positively charged.

- The concentration (#/cm^3) of conduction electrons & holes in a semiconductor can be modulated in several ways:
    1. by adding special impurity atoms (dopants)
    2. by applying an electric field
    3. by changing the temperature
    4. by irradiation

Compound Semiconductors

A semiconductor which is constituted by two or more different species of atoms is called compound semiconductor

III-V compounds: Compounds formed from elements from third and fifth groups are called III-V compounds

II-VI compounds: Compounds formed from elements from third and fifth groups are called II-VI compounds

- A compound semiconductor consisting of two elements is called binary compound. Compounds of three elements are called ternary compounds. Compounds of four elements are called quarternary compounds
- The properties of compound semiconductors are varied by varying the percentage composition of elements

Gallium arsenide

- It is the second most widely used type of semiconductor after silicon.

- It is widely used in high performance RF devices where its high electron mobility is utilised.

- It is also used as substrate for other III-V semiconductors, e.g. InGaAs and GaInNAs.

- It is a brittle material and has a lower hole mobility than Silicon which makes applications such as P-type CMOS transistors not feasible.
- It is also relatively difficult to fabricate and this increases the costs of GaAs devices.

Silicon carbide

- It is often used in power devices where its losses are significantly lower and operating temperatures can be higher than those of silicon based devices.

- Silicon carbide has a breakdown capability which is about ten times that of silicon itself.

Gallium Nitride

- This type of semiconductor material is starting to be more widely in microwave transistors where high temperatures and powers are needed.
- It is also being used in some microwave ICs.
- GaN is difficult to dope to give p-type regions

Gallium phosphide

- This semiconductor material has found many uses within LED technology.
- It was used in many early low to medium brightness LEDs producing a variety of colours dependent upon the addition of other dopants.
- Pure Gallium phosphide produces a green light, nitrogen doped, it emits yellow-green, ZnO-doped it emits red.

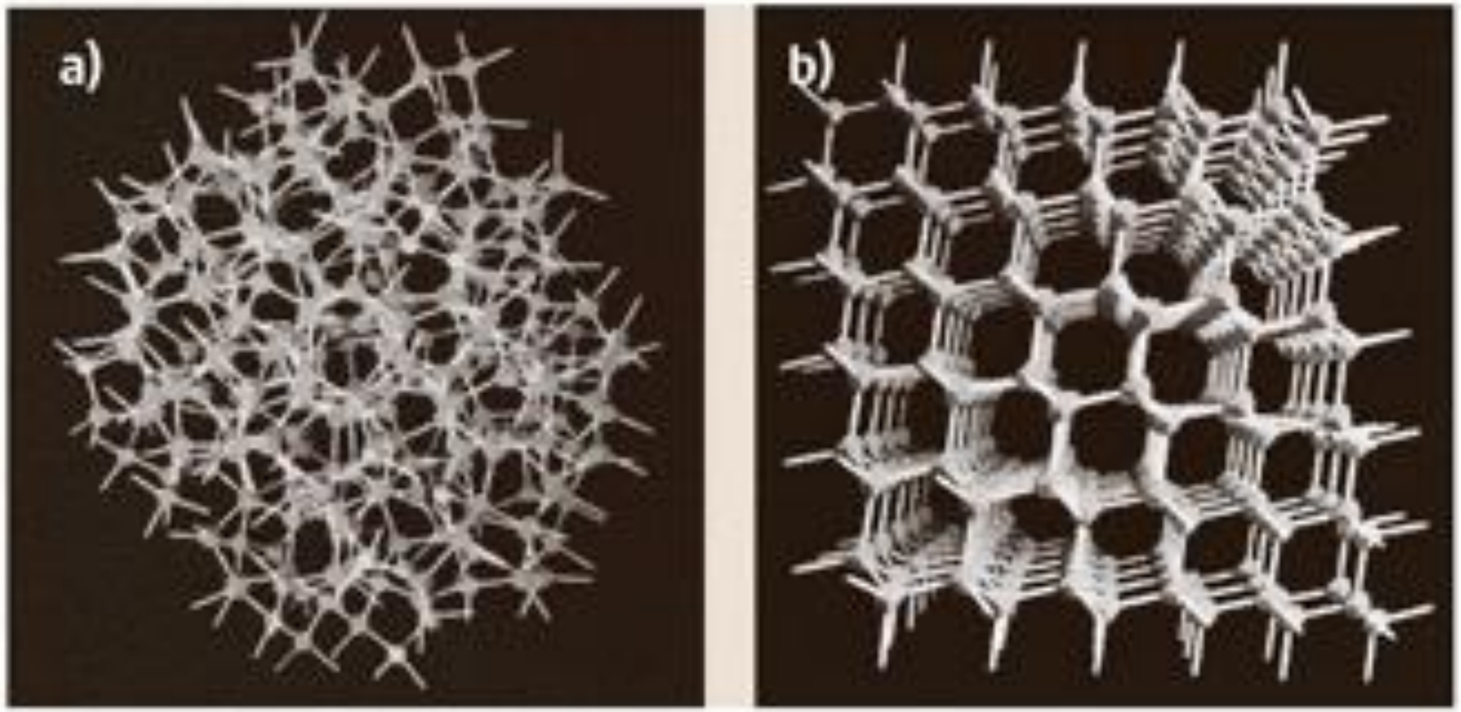
Amorphous semiconductors

- A semiconductor material which is not entirely crystalline, having only short-range order in its structure.
- A perfect crystal is that in which the atoms are arranged in a pattern that repeats periodically in three dimensions to an infinite extent.
- An imperfect crystal is that in which the atoms are arranged in a pattern that repeats periodically in three dimensions to a finite extent.

Amorphous semiconductors

- Amorphous semiconductors are electronic materials used for a wide range of applications such as solar cells, thin film transistors, light sensors, optical memory devices, X-ray image sensors etc..

- Long range disorder in amorphous network breaks down the periodic arrangement of constituent atoms



- It becomes difficult to treat the electronic states in amorphous solids mathematically
- Amorphous semiconductors are
divided into three groups: covalent amorphous semi-conductor, chalcogenide glasses and oxide glasses.
- In systems consisting of an amorphous semiconductor film between two metals, the rapid transition(switchin g) of the amorphous semiconductor from a highly resis tive state to a conductive state is possible when the ap plied voltage exceeds a threshold voltage.

Amorphous semiconductors have various practical appli cations.

- Chalcogenide glasses are used in television camera tub es
  and for hologram recording because of their transpare ncy
  to infrared radiation, high resistance, and high photose nsitivity.
-
- Dielectric films are also used in metal-dielectric semiconductor structures.

Organic semiconductors

Organic semiconductors are a class of materials that combine the electronic advantages of semiconducting materials with the chemical and mechanical benefits of organic compounds such as plastics.

Thus, the ability to absorb light, conduct electricity, and emit light is united with a material structure that can easily be modified by chemical synthesis.

Semiconductor applications such as displays, lighting panels, or solar cells may be produced with a variety of solution-processing techniques or vacuum deposition methods

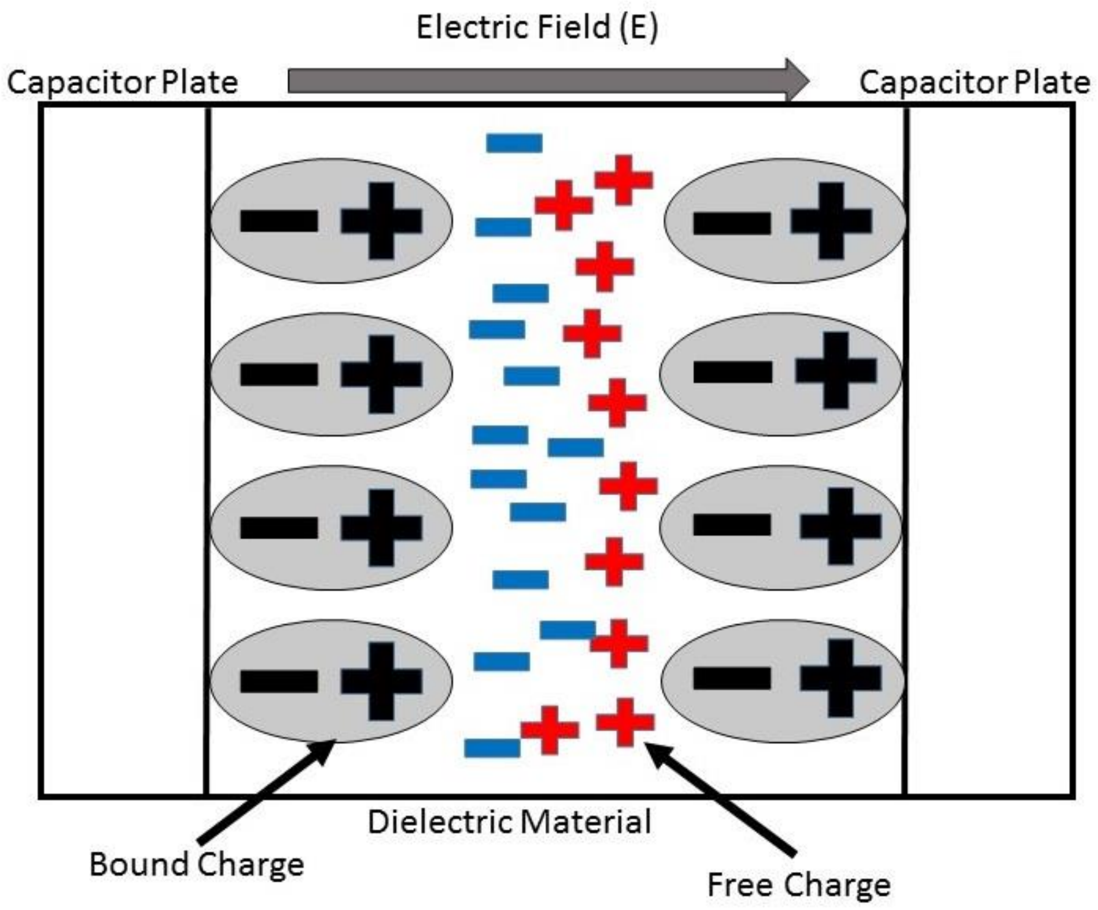
What Are “Organic Semiconductors”?

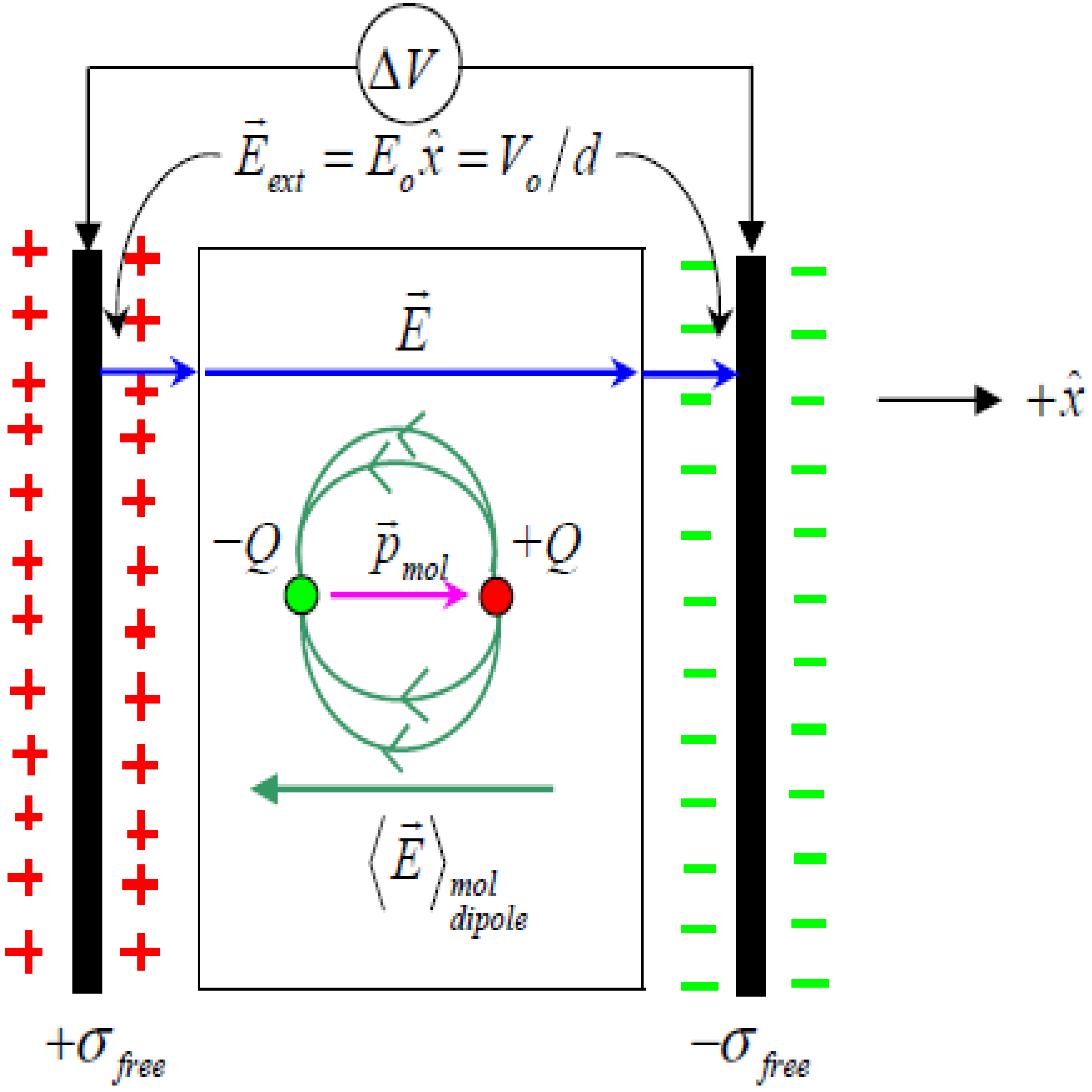
The term organic semiconductors implies (i) that the materials are mostly made up by carbon and hydrogen atoms, with a few heteroatoms such as sulfur, oxygen, and nitrogen included and (ii) they show properties typically associated with a semiconductor material.

The latter means absorption and emission of light in the visible spectral range and a degree of conductivity that is sufficient for the operation of classical semiconductor devices such as light-emitting diodes (LEDs), solar cells, and field-effect-transistors (FETs). While they show semiconducting properties, one needs to understand that the “semiconducting” nature differs strongly between inorganic and organic materials

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

Dielectric


Electric Field (E)
Capacitor Plate
Capacitor Plate
Dielectric Material
Bound Charge
Free Charge



ΔV
$\vec{E}_{ext} = E_o\hat{x} = V_o / d$
$\vec{E}$
$+\hat{x}$
$-Q$
$\vec{p}_{mol}$
$+Q$
$\langle \vec{E} \rangle_{mol\ dipole}$
$+\sigma_{free}$
$-\sigma_{free}$

- Relative permittivity
- $\epsilon_r = Q/Q_0 = C/C_o = \epsilon/\epsilon_0$

The polarization of a material is

$P = N\alpha_e E = \chi_e \epsilon_0 E$

χ term is known as the electric susceptibility of the material

N is the number of molecules per unit volume.

$\chi = \epsilon_r - 1$

$\epsilon_r = 1 + N\epsilon_e/\epsilon_0$

While this equation does relate the dielectric constant with the electronic polarizability, it only represents the material as a whole, and does not take into effect the local field, or the field experienced by a molecule in a dielectric. This field is known as the Lorentz field, and the equation to define this is given as,

$E_{loc}=E+(1/3\epsilon_{0)})P$

$\epsilon r-1/\epsilon r+2=N\alpha e3/\epsilon 0$

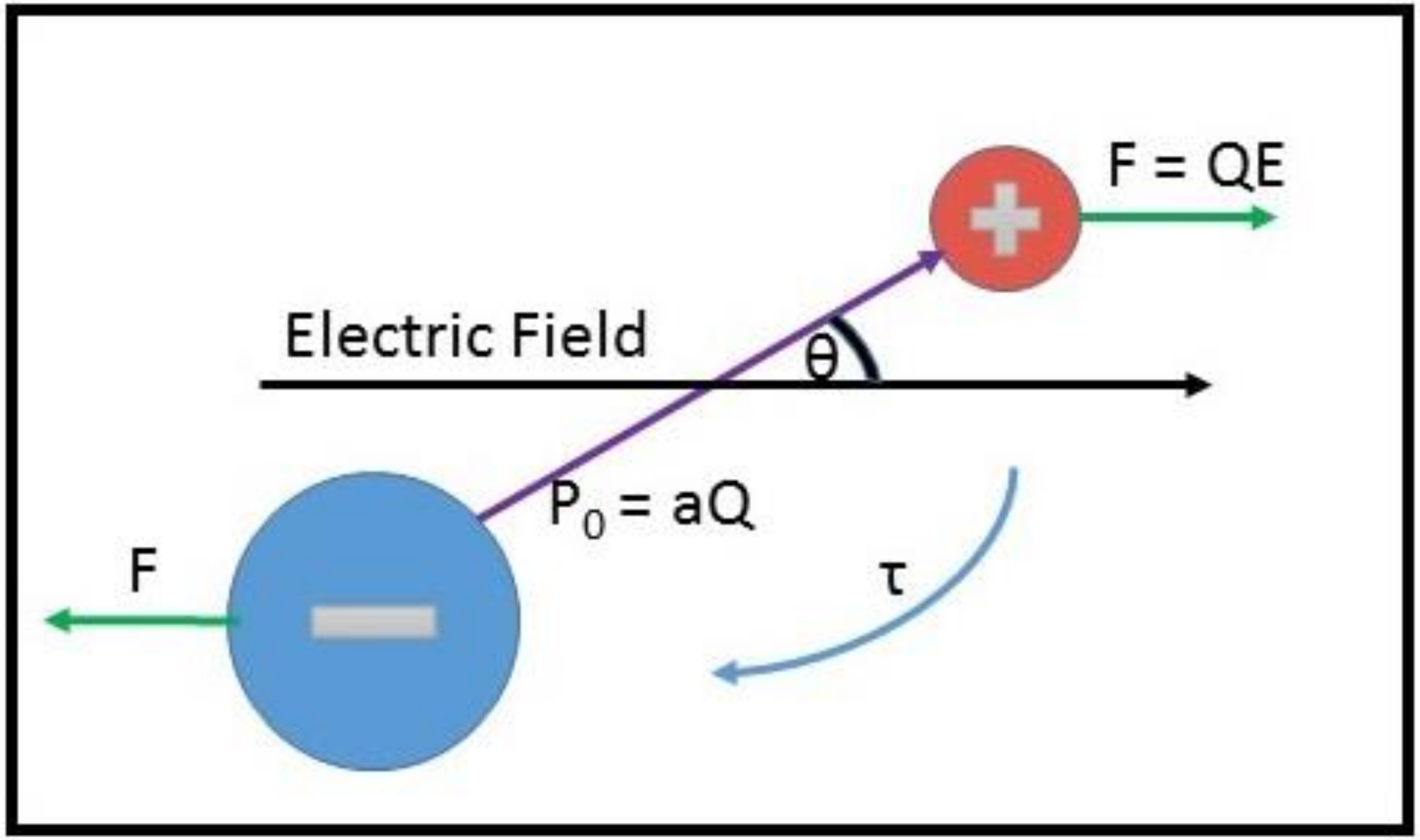
This equation is known as the Clausius-Mossotti equation and is the way to interchange between the microscopic property of electronic permittivity and the dielectric constant. In addition to knowing the electronic polarizability of a material, there are also other sub-factors, such as chemical composition and bond type that determine the total dielectric behavior of a material. However, electronic polarization is always inherent in a dielectricmaterial.

Ionic Polarization

- Ionic polarization is a mechanism that contributes to the relative permittivity of a material. This type of polarization typically occurs in ionic crystal elements such as NaCl, KCl, and LiBr. There is no net polarization inside these materials in the absence of an external electric field because the dipole moments of the negative ions are canceled out with the positive ions. However, when an external field is applied, the ions become displaced, which leads to an induced polarization. Figure 2 shows the displacement of ions due to this external electric field.

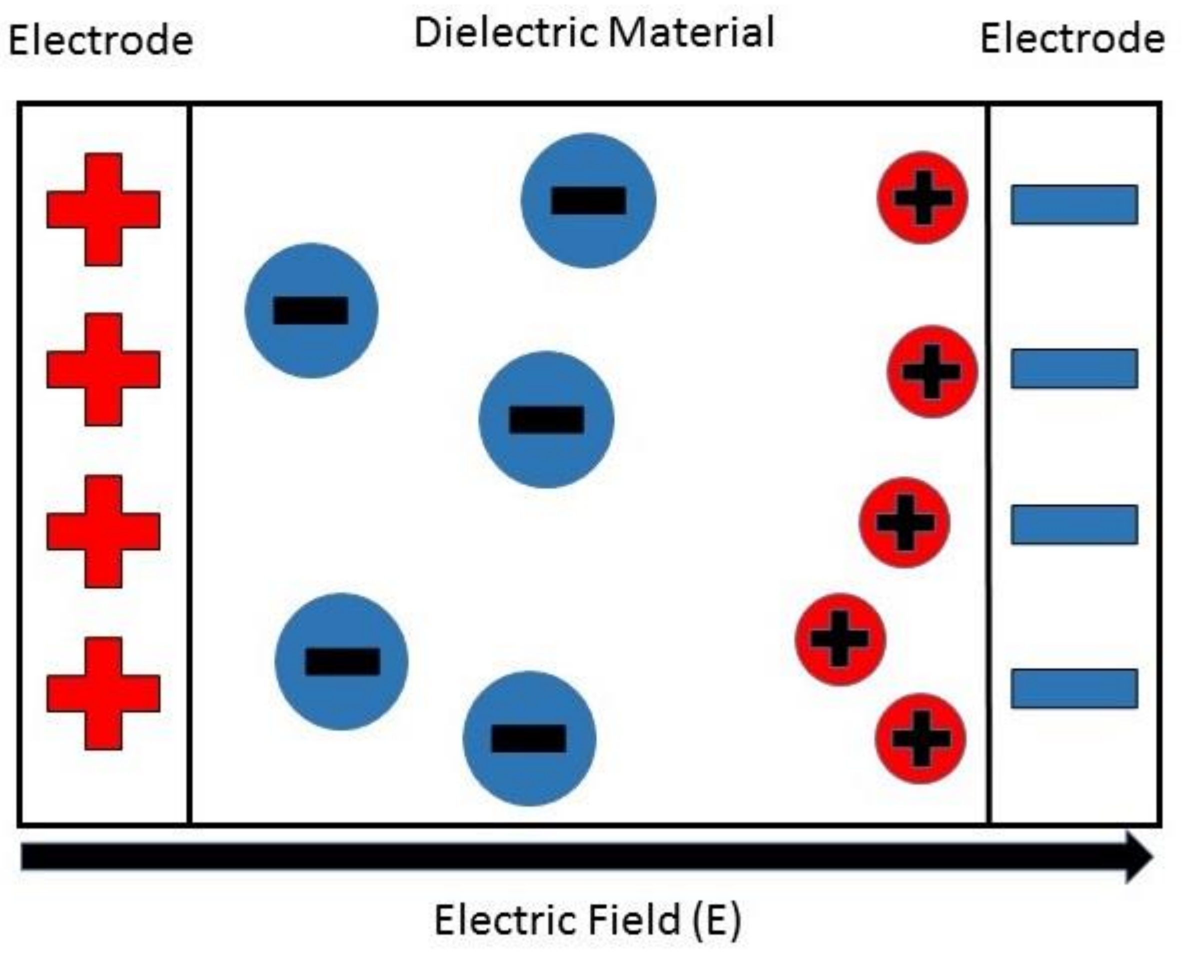
Orientational Polarization

- Orientational polarization arises when there is a permanent dipole moment in the material. Materials such as HCl and H_2O will have a net permanent dipole moment because the charge distributions of these molecules are skewed. For example, in a HCl molecule , the chlorine atom will be negatively charged and the hydrogen atoms will be positively charged causing the molecule to be dipolar. The dipolar nature of the molecule should cause a dipole moment in the material, however, in the absence of an electric field, the dipole moment is canceled out by thermal agitation resulting in a net zero dipole moment per molecule.


F = QE
Electric Field
θ
P0 = aQ
F
τ

Interfacial Polarization

- Interfacial or space charge polarization occurs when there is an accumulation of charge at an interface between two materials or between two regions within a material because of an external field. This can occur when there is a compound dielectric, or when there are two electrodes connected to a dielectric material. This type of electric polarization is different from orientational and ionic polarization because instead of affecting bound positive and negative charges i.e. ionic and covalent bonded structures, interfacial polarization also affects free charges as well. As a result interfacial polarization is usually observed in amorphous or polycrystalline solids. Figure 5 shows an example of how free charges can accumulate in a field, causing interfacial polarization.


Electrode
Dielectric Material
Electrode
Electric Field (E)

EE206-MATERIAL SCIENCE

MODULE-II

Prepared By

Rajkumar G

Assistant Professor, EEE Department

NCERC

Contents

Insulating materials and classification-properties- Common insulating materials used in electrical apparatus-Inorganic, 6 15% organic, liquid and gaseous insulators- capacitor materialsElectro-negative gases- properties and application of SF6 gas and its mixtures with nitrogen Ferro electricity.

Insulating materials

- Insulating materials are those which offer very high resistance to the flow of electric current.
- They require extremely high voltage of the order of kilo or mega volts to send a few milli-ampere of current in them

Properties of insulating material

- **Electrical properties**

1. <u>Insulation Resistance</u>

- For a good insulating material, the current should be low and the insulation resistance is large.
- Factors that affect the insulation resistance are temperature variations, moisture, voltage applied, ageing.

2. Dielectric strength

- Dielectric strength is the minimum voltage applied to an insulating material will result in the destruction of its insulating properties.
- This value is expressed in volts or kilovolts per unit thickness of the insulating material.
- This value is greatly affected by the conditions under which the material is operated. Factors affecting the dielectric strength are temperature and humidity.

- By subjecting a material to very high voltages, the material's composition will change and it will lose its insulating abilities; the voltage at which this change occurs is known as the breakdown voltage.

- Different insulators have different breakdown voltages, and are used for different purposes.

Mechanical properties

1 <u>Mechanical strength</u>

- The insulating material should have high mechanical strength to bear the mechanical stresses and strains during operation

- Temperature and humidity are the main factors which reduce the mechanical strength of an insulating material

2 Porosity

An insulating material of high porosity will absorb more moisture and thereby affect the other mechanical properties

3 Machiability and Mouldability

This property of insulating material helps us to give the desired shapes to the insulating material

4 Density

The insulating material should have low density to reduce the weight of the equipment in which insulating material is being used.

5 Brittleness

The insulating material should not be brittle. Otherwise insulators may fracture easily due to stresses

Thermal properties

1 Thermal stability

The insulating materials used must be stable with in the allowed temperatures

2. Heat Resistance

The insulating material used must be able to withstand the heat produced due to continuous operation, and remain stable during the operation

3 Thermal expansion

- Due to repeated and rapid load cycles of an equipment, corresponding expansion and contraction of the insulator occurs leading to the possibility of formation of voids

- This void formation plays a major role in breakdown phenomenon

4 Thermal conductivity

- Heat generated due to I^2R losses and dielectric losses will be dissipated through the insulator itself
- An insulator with better thermal conductivity will not allow temperature rise because of effective heat transfer through to the atmosphere

Chemical properties

1 Solubility

- In certain application insulation can be applied only after it is dissolved in some solvents
- In such cases the insulating material should be soluble in certain appropriate solvent
- If the insulating material is soluble in water then the moisture in the atmosphere will always be able to remove the applied insulation and cause breakdown

2 Hygroscopicity

- The property of insulating material by virtue of which it absorbs moisture
- The Insulating material should be non-hygroscopic
- The absorption of moisture reduces the resistivity of the insulator

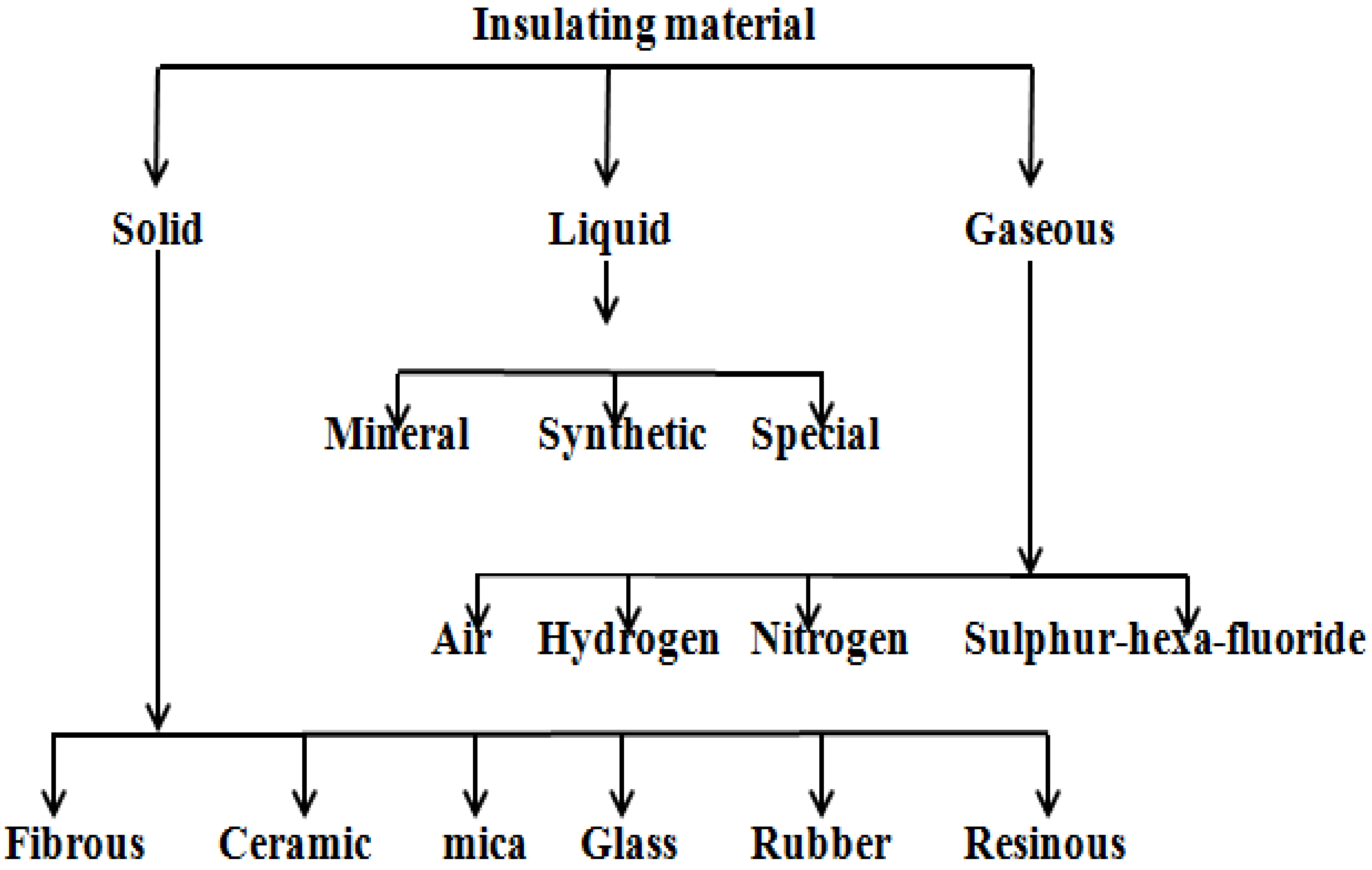
3 Chemical Resistance

- Presence of gases, acids, alkalis and salts affects different insulators differently.

- Chemically a material is a better insulator if it resist chemical action

Selection of an insulating material

- Operating temperature, pressure, operating voltage and current are to be considered for the selection of a particular material
- Easy to shape
- Availability
- Cost


Insulating material
Solid
Liquid
Gaseous
Mineral
Synthetic
Special
Air
Hydrogen
Nitrogen
Sulphur-hexa-fluoride
Fibrous
Ceramic
mica
Glass
Rubber
Resinous

Fibrous insulating material

- Fibers are from cellulose which is the main constituent of vegetable plants. They are mechanically strong and cheap. But they are hygroscopic. So they are impregnated.

- Impregnation: It is the process of treating a fibrous material with insulating material such as varnish, bitumens, drying oils, resins, etc…

- Impregnation reduces hygroscopicity and chemical and thermal deterioration
- It also helps in filling up the voids or air spaces in the material, thereby making it more homogeneous.
- Important types of fibrous materials used are: Wood, Paper, Cardboard, Insulating textiles and Asbestos

Solid Insulating Materials

1. Wood

- Properly seasoned and impregnated wood is cheap and good insulating material.
- It is used for low voltages only.
- Wood is used for making terminal boxes, switch boards, casing and capping , slot wedges in motors and generator windings, handles for tools, Instrument and equipment covers, sealing of HT and LT winding in transformers

2. Paper

- It is made from cellulose or glass or asbestos.
- Generally soft wood fibers are used in the manufacture of paper
- To improve electrical properties paper is impregnated
- It is used as layer or spacer in transformer. It is also used in capacitors, cables and windings.

3. Ceramics

- They are generally non-metallic inorganic compounds such as silicates, aluminates, oxides, carbides, borides, nitrides and hydroxides.

- Ceramics are hard, strong, dense and brittle.

- The dielectric constant of the commonly used ceramics varies between 4 and 10

- Ceramics are widely used as insulators for switches, plug holders, vacuum type ceramic metal seals etc.

- They are used as dielectric material in capacitors

4. Press board

- It is similar to paper except for its thickness. It is denser and less flexible
- It is made by passing wood pulp through heavy machines
- Its insulation resistance is 10^7 ohm meter and dielectric strength is 50 kV/mm.
- It is used for making slot wedges, end liners for stator and rotor core stacks, separatiors in transformer windings

5. Rubber

- They are organic polymers and may be natural or synthetic

- Natural rubber has limited application because of its poor stability at wide temperature range

- Hard Rubber: Increased sulphur content and prolonged vulcanization yields a rigid rubber product called hard rubber or ebonite

- Synthetic Rubbers are obtained from thermoplastic vinyl high polymers

- Rubber is widely used as an insulating material for electric wires, cables, tapes, coatings, motor winding etc

6. PVC materials

- PVC is produced when acetylene and hydrogen chloride are combined in the presence of cataylst at temperature of about 50° C.

- It is widely used in insulation for wires and cables

- PVC films, tapes and sheets are commonly used as insulation for dry batteries, conductors and cables

7. Mica

It is a mineral compound of silicate of aluminium with silicates of soda potash and magnesia

It is crystalline in nature and can be easily split into very thin sheets

It is rigid, tough and strong

Its dielectric constant varies between 5 and 7.5 and dielectric strength between 700 and 1000 kV/mm

Mica is widely used as an insulator for commutator segment separation in electrical machines, switch gear, armature windings, electrical heating devices

It is also used as a dielectric material for high frequency applications

Glass

It is a thermoplastic inorganic material obtained by fusion of different oxides and cooling in such a way that it does not crystallize but remains in amorphous state

The different raw materials used are sand, boric acid, soda, potash, chalk, magnesite, dolomite, red lead, kaoline and feldspar

- Glasses are normally transparent, brittle and hard
- They are resistant to most of the chemicals
- They have low dielectric loss, high dielectric strength
- Glass is widely used as bushings, line insulators, fuse bodies etc…

Different types of glasses are

Quartz or silica glass

Borosilicate glass

Fibre glass

Liquid Insulating materials

i) Mineral insulating oil

- These are obtained from crude petroleum by distillation and have high oxidation resistance and thermal stability
- Eg. Transformer oil, cable oil, capacitor oil
- Transformer oil is used for insulation and cooling of transformers
- It transfers heat from windings and core to the cooling surfaces by convection

ii) Synthetic insulating oil

- Now a days synthetic oil is used as an insulator in transformers in the place of transformer oil because synthetic oils are very much resistant to oxidation and to fire hazards

- Due to longer life and safety in operating conditions, synthetic oil is used as coolant and insulator in HV transformers

Eg: Askarels, aroclors, sovol and sovtol

iii) Special insulating oils

- Vegetable oils, vaseline and silicon liquids come under this group.
- Silicon liquids have thermal stability up to 200˚ C and are costly
- The dielectric strength of these liquids is same as that of mineral oils
- They are used in HV transformers

Gaseous insulating materials

i) Air

- Most important insulating material available in nature
- The dielectric constant of air increases linearly with the increase of pressure
- The power loss is zero
- It is used in air condensers
- Air can be used for insulation only in low voltage applications since at higher field strengths air may get ionised

ii) Nitrogen

- Nitrogen is chemically inert
- It prevents oxidation and reduces the rate of deterioration
- In oil filled transformers, the nitrogen is used to replace oxidizing atmosphere
- Nitrogen is also used in capacitors and cables under pressure

iii) Sulphur hexafluoride:

- It is produced when sulphur is burnt in fluorine atmosphere
- It has high dielectric strength
- It has superior cooling properties than those of air and nitrogen
- It is used in transformers, electric switches, Van de Graff generators, voltage stabilizer and X-ray apparatus

iv) Inert gases

They are used in electronic tubes and discharge tubes as insulators

Materials used for transformers

- Air cooled and oil cooled transformers – **fibrous (class A) materials**
- Taping the coils of air cooled transformers – **cotton or oiled cambric**
- Insulation between core and coils – **synthetic resin-bonded paper or treated press board**
- Insulating conductors of oil cooled transformers – **cotton tape**
- Spaces between packing between coils – **press board or press paper**

Materials used for instruments and magnet wires

- Main requirements:
  - Flexibility
  - Thinness
  - Rapidity of application to wire
  - Ability to withstand the stress actions during the process of winding
- Materials used are:
  - Enamel
  - Cotton
  - Rayon
  - Silk
  - Fibrous glass

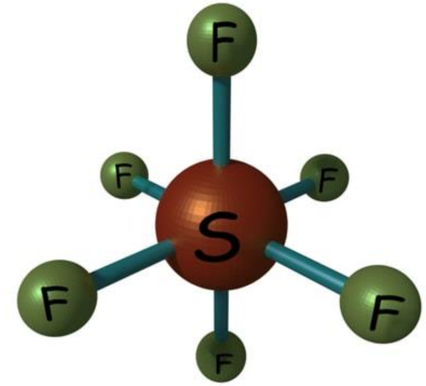
Materials used for machines

- AC and DC motors for industrial installations – **Class A** materials
- Turbo alternators – **Class B** materials
- Insulation of commutators – **Mica**
- For moisture proofing and increasing dielectric strength of fibrous material – **varnishes and impregnating compounds**
- Terminal boards of DC and AC machines – **laminates of paper, cotton cloth, asbestos**
- Insulating terminals of high voltage machines – **porcelain**

Electronegative gases

- **Electronegativity**, is a chemical property that describes the tendency of an atom to attract electrons towards itself.
- One of the important electronegative gas is **sulphur hexa fluoride SF6** which is mainly used in circuit breakers.

Sulphur hexafluor



- SF_6 gas is highly electronegative. Due to high electronegativity, it absorbs free electrons which produced due to arcing between contacts of circuit breaker.
- Combination of free electrons with molecules produces heavy and big ions, which have very low mobility.
- Because of absorption of free electrons and low mobility of ions sulphur hexafluoride has very excellent dielectric property.
- Dielectric strength of sulfur hexafluoride gas is about 2.5 times more than that of air.

Physical properties of sf_6

- It is highly electronegative.
- Colorless.
- Odorless.
- Sulphur hexafluoride (SF6) gas has good dielectric properties.
- Density : heavy gas with density 5 times that of air at *20* ° C and atmospheric pressure and has low solubility in water
- Good arc quenching property.
- Nontoxic. Pure SF6 gas is not harmful to health. However, impure SF6 gas contains toxic impurities.

- Non-flammable.
- Sulphur hexafluoride gas is of low cost if manufactured on a large scale.
- Gas at normal temperature and pressure.
- The possibility to obtain the highest performance, up to 63 kA, with a reduced number of interrupting chambers
- Short break time .
- The dielectric strength of the gas increase with pressure and is more than that of the dielectric oil at high pressures.

- High electrical endurance, allowing at least 25 years of operation without reconditioning
- Reliability and availability
- Low noise levels
- Can be liquefied by compression.
- Good cooling characteristics.
- Increases the interrupting capability of circuit breakers.

applications

1. High voltage metal enclosed cables,
2. High voltage metal clad switchgear,
3. Capacitors,
4. Circuit breakers,
5. Current transformers,
6. High voltage bushing,
7. Gas insulated substations.

- Sulphur hexafluoride gas is of low cost if manufactured on a large scale. It is transported in liquid from cylinders. Before filling the gas, the circuit breaker is evacuated to the pressure of about 4mm of mercury so as to remove the moisture and air. The gas is then filled in the Circuit Breaker

breakdown of sf_6

- The conductor in SF6 insulating equipment are supported on epoxy or porcelain insulators. The flashover invariably takes place along the surface of the support insulators.
- The breakdown can occur at extremely low values if the insulators supports are covered by moisture and conducting dust. Hence the insulators should be extremely clean and should have anti-tracking properties.
- The breakdown is initiated at sharp edges of conducting parts and parts having maximum stress concentration.
- Good stress distribution is very important in SF6 insulated equipment.

Mixture with nitrogen

- SF6 gas maintain high dielectric strength even when diluted by air (Nitrogen).
- 30% SF_6 + 70 % of air, by volume, has a dielectric strength twice that of air (at the same pressure). Below 30% by volume, the dielectric strength reduces quickly.
- Presently most important used one is mixture of Nitrogen and SF6
- The breakdown voltage and the extension of the discharge is the main advantage of mixture of nitrogen with SF6.

ferroelectricity

A group of dielectric materials that display spontaneous polarization, or in other words, they possess polarization in the absence of an electric field.

- If the center of gravity of the positive and negative charges in a body do not coincide in the absence of an applied electric field, the substance has an electric dipole moment and is said to be spontaneously polarized. Such a substance is called ferroelectric.
- It contains small regions which are polarized in different directions even in the absence of an electric field.
- When temperature exceeds a certain value called the curie point the substance loses its ferroelectric properties.

characteristics

1. They have a high dielectric constant which is **non linear**, i.e. it depends to a considerable extend on the intensity of the electric field.
2. They exhibit **hysteresis loop**, i.e. the polarization is not linear function of applied electric field.

Common ferroelectric materials

The common ferroelectric materials known as :

1. Rochelle salt ($NaKC_4H_4O_64H_2O$)
2. Potassium dihydrogen phosphate (KH_2PO_4)
3. Potassium dideutorium phosphate (KD_2PO_4)
4. Potassium dihydrogen argon sulphate (KH_2ArSO_4)
5. Barium titanate ($BaTiO_3$)
6. Strontium titanate ($SrTiO_3$)
7. Cadmium titanate ($CdTiO_3$)
8. Lead titanate ($PbTiO_3$)
9. Lead zirconate ($PbZrO_3$)
10. Mixed titanate of (5), (6), (7), (8), and (9)
11. Silicon carbide (SiC)
12. Boron nitride (NB)
13. Silicon nitride (N_4Si_3)
14. Aluminium nitride (NAl)

Some ferroelectric materials

- **<u>Rochelle salt</u>**
  - It is a salt of sodium, potassium and tartaric acid.
  - It has two curie points.
  - This salt is crystalline material soluble in water and very high hygroscopic material.
- **<u>Barium titanate</u>**
  - Produced by firing equimolecular quantities of titanium dioxide and barium oxide.
- **<u>Boron nitride</u>**
  - Nitrides are used for extremely heat resistant dielectrics.

Hysteresis loop

- Fig shows the polarization versus electric field curve of a ferroelectric material. The hysteresis loop obtained is similar to the hysteresis loop of a ferromagnetic material.

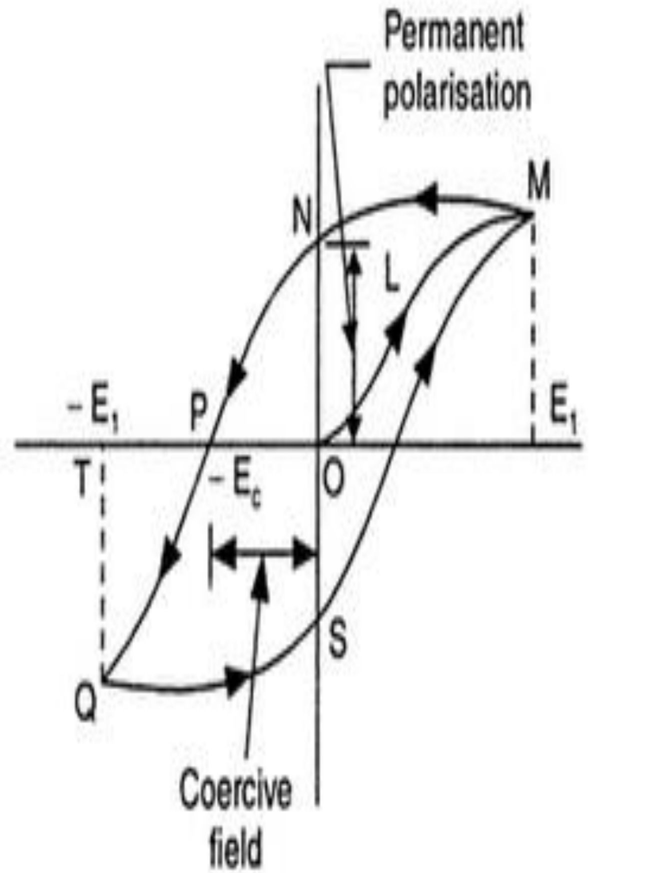
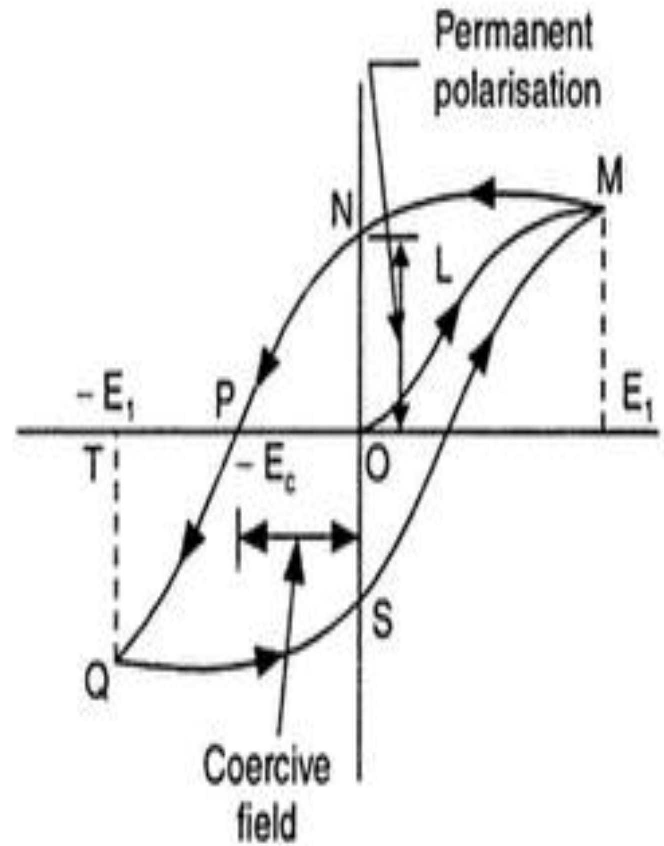


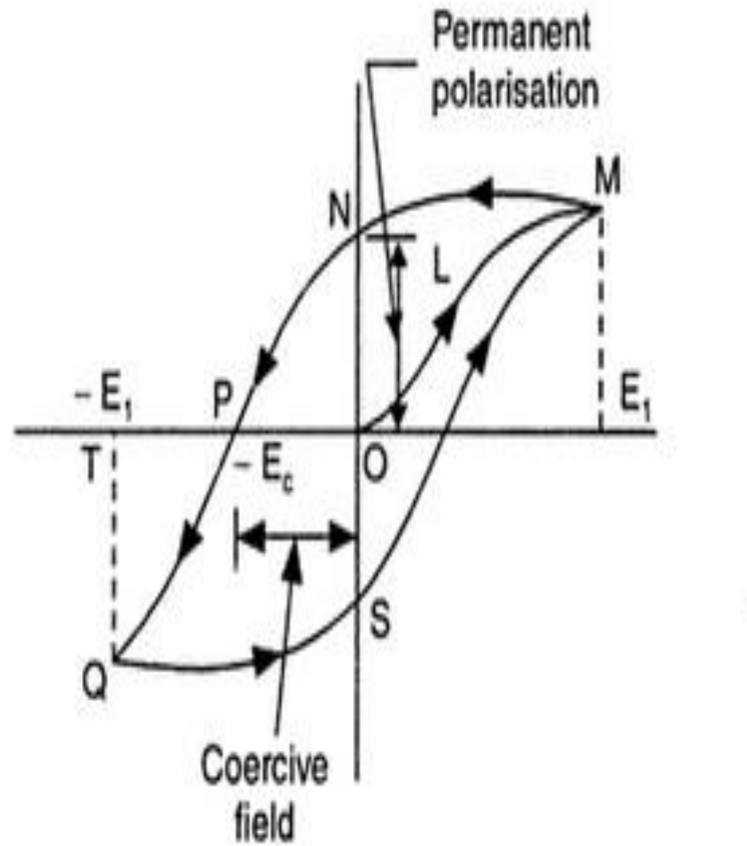
Fig. 5.4. Hysteresis curve for a ferroelectric material.

- Consider a pure specimen with no initial polarization…….
- When applied electric field E increases, the polarization increases along the curve OLM. This is called initial polarization curve.
- Then the electric field is reduced and thus polarization reduces along the path MNPQ. When E= O , there exists a certain residual polarization or remanant polarization P_r. Or we can say that the material is spontaneously polarized.



5.4. Hysteresis curve for a ferroelectric material.

- On further reducing the electric field E in the negative direction, the polarisation ultimately reduces to zero at E=E_c at point P on the curve. This electric field E_c is called coercieve field.
- If the electric field is made further negative, the polarisation also becomes negative and finally reaches a value - E_1at Q.
- On increasing the E from - $E_1$to +E_1 polarisation moves along the curve QSM.The closed curve MNPQSM constitute the hysterisis curve.



5.4. Hysteresis curve for a ferroelectric material.

Curie point

The temperature dependence of the permittivity of ferroelectric materials is very important.

- The temperature at which the permittivity has a sharply defined peak is called the curie point.
- Ferro electric materials below curie point have special properties.
- Above the curie temperature the materials have no ferroelectric properties and become ordinary insulating materials.

Applications of ferroelectric materials

- Ferro electric materials are used for applications like

<u>Ferroelectric capacitors</u>

They have large dielectric constant which permits the use of physically small capacitors.

MODULE 3
Dielectric Breakdown

MODULE-III

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Syllabus

Mechanism of breakdown in solids, liquids and gases – Dielectric Breakdown – Intrinsic breakdown – Electro mechanical breakdown – Townsends criterion – Streamer mechanism –suspended particle theory – ageing of insulators – Application and breakdown of vacuum insulation – treatment and testing of transformer oil

Breakdown in Gaseous dielectrics

- Breakdown in gases begins with ionization due to collision of electrons (intrinsic breakdown).
- Breakdown is accelerated by secondary emission of electrons from cathode (Townsends criterion).

Breakdown in Liquid dielectrics

Liquid dielectrics are sub classified into three. They are

1. Contaminated liquid dielectrics.
2. Technically pure liquid dielectrics.
3. Degassed high purity liquid dielectrics.

- In contaminated liquid dielectrics, breakdown occurs due to the formation of conducting bridges between the electrodes by droplets of emulsified water and suspended particles(**Suspended Particles Theory**).
- In technically pure liquid dielectrics, breakdown is initiated by ionization of gas contained in the liquid. Here gas will act as a conducting medium leading to breakdown.
- In degassed high purity liquid dielectrics, breakdown is evidently due to collision ionization (intrinsic breakdown).

Breakdown in Solid dielectrics

Three types of breakdown are possible in solid dielectric.

1. Electro thermal breakdown
2. Purely electrical breakdown
3. Electro mechanical breakdown.

Electro thermal breakdown

It occurs due to heat produced by dielectric loss. If rate of generation of heat in electrons are greater than the heat dissipated in the surroundings, temperature of dielectric increases eventually, results breakdown

Purely electrical breakdown

It occurs due to intrinsic breakdown.

Electro mechanical breakdown

- When an electric field is applied to a dielectric between the electrodes, a mechanical force will be exerted on dielectric. This will create force of attraction between the surface charges of dielectrics. This compression due to force of attraction decreases the insulation thickness, there by creates breakdown.

Dielectric Breakdown

When a dielectric losses its insulation resistance and permits large current to flow throw it is called dielectric breakdown. Important types of dielectric breakdown are

1. Intrinsic breakdown.
2. Thermal breakdown.
3. Electrochemical breakdown.
4. Discharge breakdown.
5. Defect breakdown.

Intrinsic Breakdown

Intrinsic breakdown are of two types

- 1. Electronic breakdown
- 2. Avalanche or Streamer Breakdown

Electronic Breakdown

- When an electric field is applied to an atom, electrons gains energy from electric field and crosses forbidden energy gap from valance band to conduction band.
- When this process is repeated, more and more electrons are available in conduction band, eventually leading to breakdown.

Avalanche Breakdown

- When an electric field is applied to an atom, electrons will drift from cathode to anode.
- During this motion, electrons gains kinetic energy from electric field and losses it during collision.
- Collision occurs due to sudden increase in applied voltage(impulse voltage) within a short time (about 10-8 seconds)
- During collision, free electron collide with a neutral particle and gives rise to two new electron and +ve ion.(ie ionization takes place)

This process repeats until avalanche exceeds a critical size.

Mathematically it is expressed as

$e^- + A \rightarrow e^- + A^+ + e^-$ [if ε › vi]

Here e – = electron

A = atom

A+ = +ve ion

Electrochemical Breakdown

- Electrochemical breakdown have a close relationship with thermal breakdown.
- When temperature rises, mobility of ions increases and hence electro chemical reaction takes place.
- The electro chemical reaction gradually decreases the insulation resistance and finally creates the dielectric breakdown.

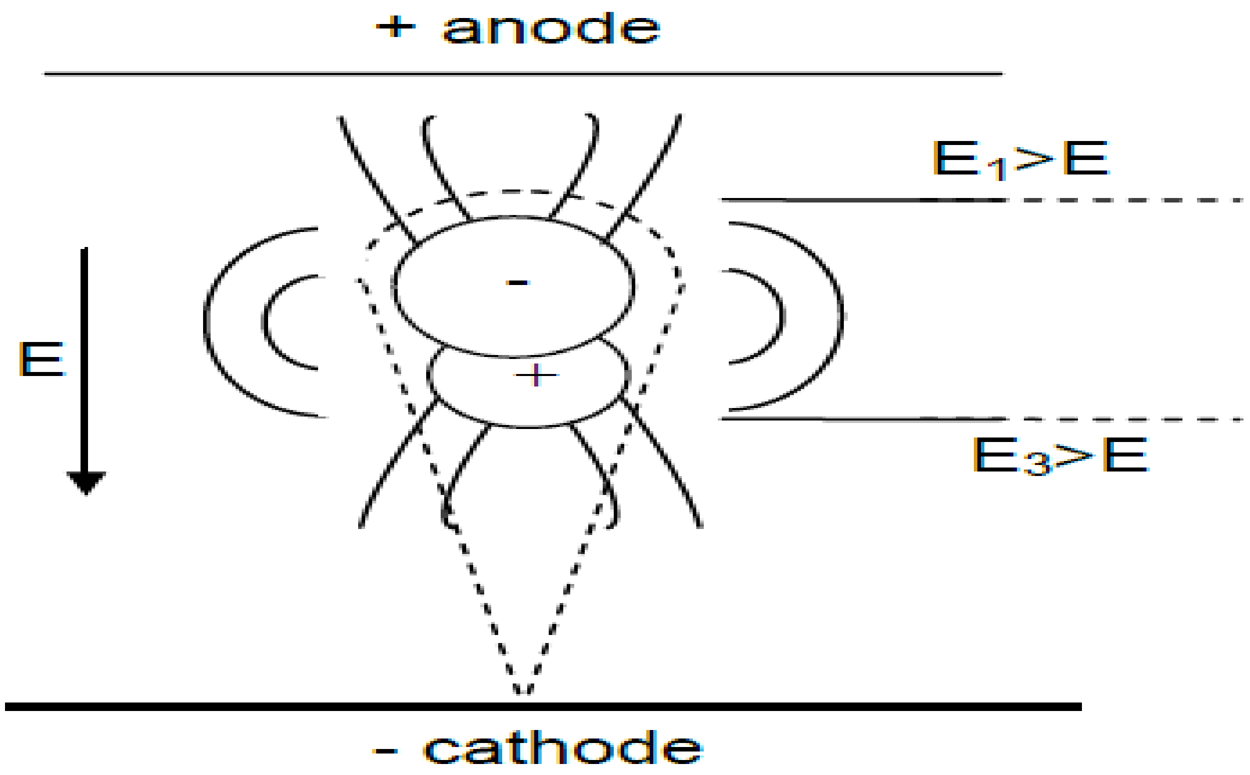
Discharge Breakdown

- Gas bubbles contained in the liquid/ solid dielectric requires small ionization potential than main dielectric.
- In the dielectric, gas bubbles ionize first and bombard of gaseous ions causing electric breakdown in it.

Defect Breakdown

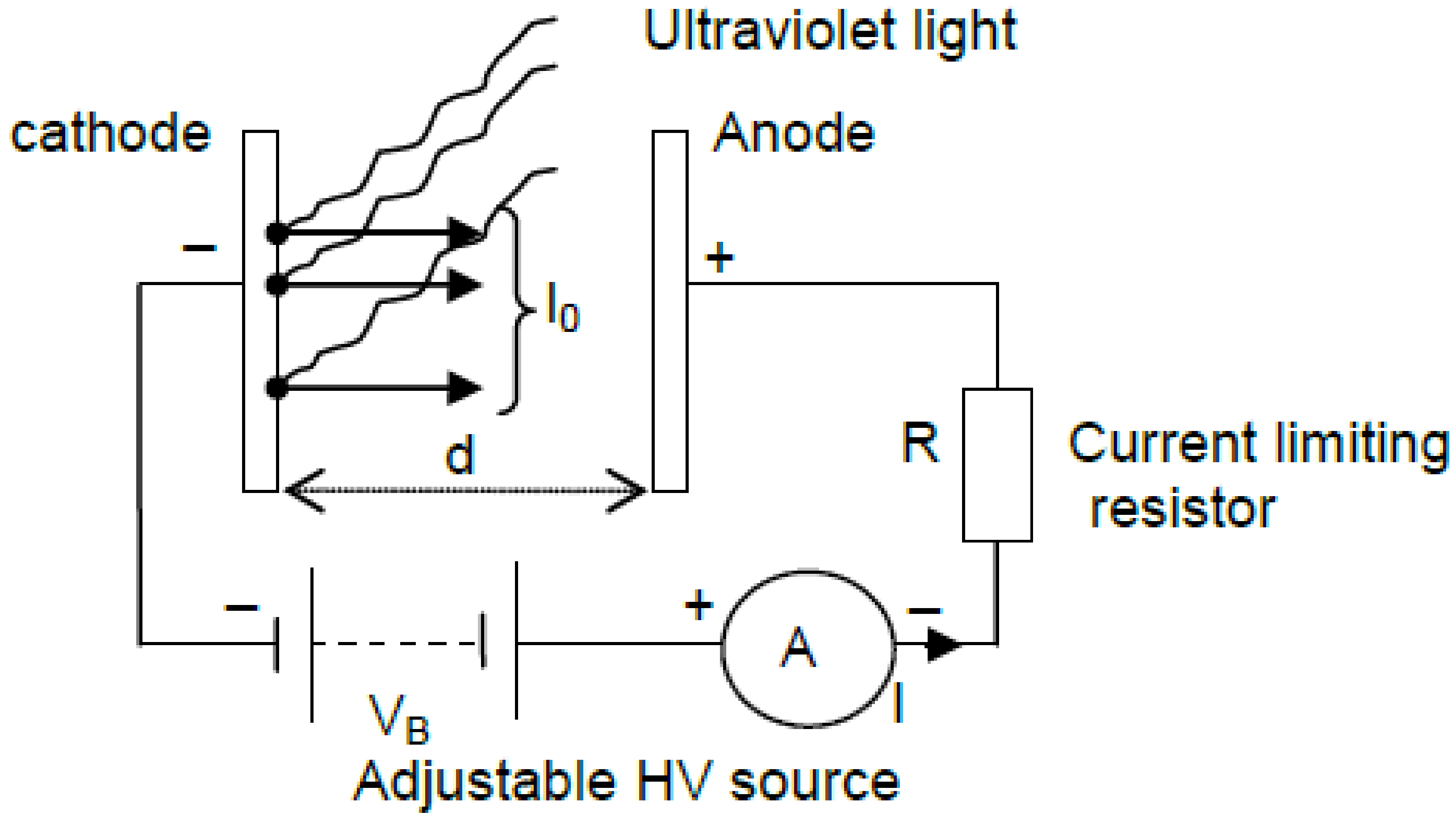
- The cracks and pores in the surface of dielectric collect moisture and other impurities, which leads to breakdown.

Streamer Mechanism of Breakdown



- As per streamer mechanism, breakdown not only occurs due to ionization but also due to ionization process the gas pressure and the geometry of the gap.
- Streamer mechanism state that, a single electron starting at the cathode by ionization builds up an avalanche that crosses the gap. The electrons in the avalanche move very fast compared with the positive ions.
- By the time the electrons reach the anode the positive ions are in their original positions and form a positive space charge at the anode. This enhances the field, and the secondary avalanches are formed from a few electrons produced due to the photo-ionization in the space charge region.
- This occurs first near the anode where the space charge is maximum and a further increase in the space charge. This process is very fast and the positive space charge extends to the cathode very rapidly resulting in the formation of a streamer.

Townsends Criterion



- Townsends criterion explains generation of successive secondary avalanches to produce breakdown.
- Here additional electrons are produced at cathode by some external forces like UV light falling on it.
- This additional electrons themselves makes more ionization by participate in collision.
- In Townsend’s type of discharge in gas, electrons get multiplied due to various ionization process and finally an electron avalanche is formed.

Suspended Particle Theory

- The presence of solid impurities like fibers or dispersed solid particles experiences force due to applied field.
- These solid particles contained in the liquids are aligned due to the force generated by applied electric field forms a stable chain bridge causing breakdown of liquid dielectric between the electrodes.
- This process is called suspended particle theory.

Testing of Transformer Oil

- The transformer oil is filled in the vessel of the testing device. Two standard compliant test electrodes with a typical clearance of 2.5 mm are surrounded by the dielectric oil.
- A test voltage is applied to the electrodes and is continuously increased up to the breakdown voltage with a constant slew rate of e.g. 2 kV/s.
- At a certain voltage level breakdown occurs in an electric arc, leading to a collapse of the test voltage.
- An instant after ignition of the arc, the test voltage is switched off automatically by the testing device. Ultra fast switch off is highly desirable, as the carbonization due to the electric are must be limited to keep the additional pollution as low as possible.
- The transformer oil testing device measures and reports the root mean square value of the breakdown voltage.

- After the transformer oil test is completed, the insultaion oil is stirred automatically and the test sequence is performed repeatedly. (Typically 5 Repetitions, depending on the standard)
- As a result the breakdown voltage is calculated as mean value of the individual measurements.
- Conclusion: The lower the resulting breakdown voltage, the poorer the quality of the transformer oil!

Breakdown of Vaccum Insulation

- Primary breakdown process in vaccum occurs due to field emission of electrons from cathode.
- When an electric field is applied to a vaccum metal surface, the surface potential energy barrier is thinned sufficiently so that free electrons entered in to vaccum, which leads to breakdown.
- Emission of additional electrons and positive ions with generation of photons from additional sources increase secondary emission process, which also lead to breakdown.
- If energy gained by electrons (acceleration due to collision) exceeds a critical value, localized heating would produce a vapour cloud , which is also suffient for breakdown.

Applications of Vaccum Insulators

- Particle accelerators
- X-ray and field emission tubes
- Electron microscopes
- Capacitors
- Circuit Breakers

EE206-Material Science

MODULE-IV

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SYLLABUS

- Magnetic Materials – Origin of permanent magnetic dipole moment – classification of magnetic materials – curie-wiess law – Soft and Hard Magnetic Materials – Properties and applications of irons, alloys of irons- Ferrites – Magnetic materials used in electrical machines, instruments and relays

Origin of permanent magnetic dipole moment

- In 1913, Niels Bohr & Ernest Rutherford introduces Bohr theory.
- Bohr theory depicts that atom has a small +vely charged nucleus surrounded by electrons that travel in circular orbits.
- In all atoms, electrons revolving around the nucleus in different orbits. This revolving electron constitutes an electric current in these orbits. This current forms magnetic dipoles.
- Thus permanent magnetic dipoles are originated from spinning motion of electrons in an atom.

Classification of magnetic materials

Based on arrangement, magnetic materials are classified as

- Diamagnetic materials
- Paramagnetic materials
- Ferromagnetic materials
- Antiferro magnetic materials
- Ferrimagnetic materials

Diamagnetic materials

- Permanent magnetic dipoles are absent on diamagnetic materials
- If an external magnetic field is applied to a diamagnetic material it induces a magnetization M in opposite direction to the applied field intensity H.
- This means that relative permeability μr of diamagnetic materials are negative Magnetic susceptibility is independent of applied magnetic field strength.
- Eg:- Hydrogen, Bismuth

Paramagnetic Materials

- Permanent magnetic dipoles are present on paramagnetic materials.
- In the absence of external field, the dipoles are randomly oriented. Hence the net magnetization in any given direction is zero.
- When paramagnetic materials are placed in a magnetic field, it attracts the magnetic lines of force.
- Susceptibility is positive and depends greatly on temperature.
- Spin alignment is random.
- Magnetic susceptibility is independent of applied magnetic field strength.
- Eg:- Aluminium, Platinum

Ferromagnetic materials

- Due to large internal magnetic field, the permanent magnetic dipoles are aligned in the same direction with same magnitude and consequently large spontaneous magnetization results even in the absence of applied field.
- They exhibit magnetic hysteresis.
- During heating they lose their magnetization slowly.
- Susceptibility is positive and large.
- It consists of number of small regions which are spontaneously magnetized.
- Spin alignment is parallel in same direction
- Eg:- Iron, Nickel, Cobalt

Anti-ferro magnetic materials

- Spin alignment of neighboring atoms are anti-parallel.
- Susceptibility greatly depends on temperature.
- Susceptibility is positive and large.
- Initial susceptibility increases slightly with temperature and beyond Neel temperature the susceptibility decreases with temperature.
- Eg:- Ferrous oxide, Manganese oxide, Chromium oxide & salts of transition elements

Ferri-magnetic Materials

- In ferrimagnetic materials, unequal magnetic moments are aligned antiparallely.
- Susceptibility is positive and large.
- Actually ferri-magnetic materials are composed of different transition metals. Due to that large magnetization occurs.
- Eg:- Ferrous ferrite, Nickel ferrite

Curie –Wiess Law

Curie –Wiess shown the variation of susceptibility (X) of ferromagnetic materials.

Also it shows the temperature dependence of spontaneous magnetization.

X = I/H = C / T- θ

This is called Curie-Wiess Law.

Here X = susceptibility

C = Curie constant

T = operating temperature

Θ = Curie temperature

- As per Curie-Wiess Law, the material is ferromagnetic below curie temperature and becomes paramagnetic above curie temperature.

- We must ensure the operating temperature is always below the curie temperature for maintain magnetic properties of materials.
- Thermal energy increases with increase in temperature which randomizes more and more of the parallel spins and at curie temperature, the parallel alignment of all spins vanishes resulting in the zero value of spontaneous magnetization. After that the substance becomes paramagnetic.
- A critical temperature at which the alignment of magnetic moments vanishes is called curie temperature.

Soft and Hard Magnetic Materials

Description	Soft magnetic materials	Hard magnetic materials
Area of hysteresis loop	smaller	larger
Hysteresis loss	Less	more
Permeability	larger	smaller
Magnetic reluctance	low	high
Susceptibility	low	high
Retentivity	smaller	larger
Coersivity	smaller	larger
Magneto-static energy	smaller	larger
Magnetization	easier	difficult
Demagnetization	easier	difficult
Eddi current loss	Less	more
Mechanical hardness	Less	more
Need of magnetic force for	Less	more

Ferrites

- Ferrites are compounds of two metallic oxide in which one is always iron oxide.
- Symbolically ferrites may be designated as (MetO. Fe2O3)
- Here “Met” stands for metals like Ni, Mn, Zn, Cu, Fe etc.
- In ferrites, unequal magnetic moments are aligned antiparallely.
- Ferrites with narrow hysteresis loop forms soft magnetic materials which are used for making audio and television transformers, gyrators, induction cores etc.
- Ferrites with large hysteresis loop forms hard magnetic materials which are used for making permanent magnets for eg:- Barrium ferrite (BaO6Fe2O3)

Properties:

- High resistivity
- Low power loss at high frequency
- Poor mechanical strength

EE206-Material Science

MODULE-V

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SYLLABUS

Superconductor- Basic concept – Types – Characteristics – Applications
Solar energy materials – photo thermal conversion – solar selective coating for enhanced thermal energy collection – Photo-voltaic conversion – Silicon, GaAs , CdS , organic solar cells

Superconductors

- A superconductor is a conductor with zero/ negligible resistance.
- Superconductors are those elements, compounds and alloys of metals and non-metals which exhibit extra ordinary magnetic and electric behavior at extremely low temperature.
- Normal conductors become superconductor above transition temperature Tc (It is a temperature atwhich electrical resistivity of metal falls to zero).

Types

- Superconductors are broadly classified in to two

1) Type-I Superconductors

2) Type-II Superconductors

- Type-I superconductor consist of basic conductive elements that are used in electrical devices
- Sulpher-17°k
- Aluminium -4.15°k
- Mercury -1.17°k
- Lead -7.2°k
- Zinc - 0.85°k

Type-II superconductors are made from alloys of metals.

- CuS 1.6°k
- Nb3Sn 18.3°k
- Pb2Au 7°k

Alloys Tc

- ceramic 34°k

Properties / Characteristics of superconductors

Magnetic flux density = 0

Relative permeability = 0

Specific resistance = 0

Magnetic susceptibility = -1

Power loss = 0

Applications of superconductors

- Low loss power cables
- RF & microwave filters
- Magnetic Resonance Imaging
- Nuclear magnetic resonance
- Maglev trains
- Switching elements

Photo –Thermal Conversion

- Conversion of solar energy directly into heat energy is called photo thermal conversion.
- A solar collector is used to absorb solar radiation and converts it in to heat energy.

Solar Coatings

An efficient way to maximize the harnessing of solar energy is to apply coatings of some specific materials to absorber surface. Coatings are used for this purpose. Coatings are classified into two

i) Non-selective solar coatings

ii) Selective solar coatings

Non-selective solar coatings

- Non-selective solar coatings increases absorptivity and emissivity
- In solar thermal applications, a coating should have high absorptivity, but a low emissivity. So that it retains the trapped thermal energy.
- This limits the applicability of non-selective coatings for solar thermal conversion technology.
- Example: Black paint

Solar Selective Coating for Enhanced Thermal Energy Collection

- The solar selective coatings allows incoming solar radiations to pass through it and blocks the emittance of longer wavelength thermal radiations to achieve high temperature.
- Reflection and transmittance properties of optical components are selectively modified/ enhanced by using solar selective coatings,.

Solar selective coatings are mainly classified into three

- i) Cold mirror coatings
- ii) Heat mirror coatings
- iii) Anti-reflection coatings

Cold mirror coatings

- Cold mirror coatings are designed to reflect visible light and to transmit infrared radiation/heat.
- So cold mirrors are work as heat transmitting filters and at the same time they offer very high visible light reflection.

Properties:

- Very high optical reflection
- Excellent reflection uniformity
- High operating temperature (upto 400°C)
- Good mechanical stability
- Designed for incidence angle upto 45°

Applications:

- Scanners and barcode reader optics
- IR filters
- Laser beam separation

Heat mirror coatings

- Heat mirror coatings are designed to reflect infrared radiation/heat and to transmit visible light.
- So hot mirror is used to remove undesired infrared energy from light energy.
- Such mirrors reflects IR wavelength while they are transparent in visible spectrum.

Properties:

- Very good infraredf reflection upto 1100nm
- High and neutral optical transmittivity
- High operating temperature (upto 400°C)
- Transmits cold light
- 100% dielectric multy layer construction

Applications:

- Optical IR mirrors
- Mirror for eye tracking system
- IR photography filters
- Lens system protection
- IR imaging filters

Anti-reflection coatings

- Anti-reflection coatings are used to reduce reflection losses by increasing efficiency of transmittance of visible light with the help of multi layer construction with different refractive indices.
- Anti-reflection coatings consist of alternative thin film coated layers each with different refractive indices. This helps to collect light energy of different wavelengths.

Properties:

- Very low residual reflection.
- High transmittance of visible light
- Low light absorptivity.
- Broadband multilayer coatings

Applications:

- Laser scanner optics
- Holography applications
- Camera lens optics
- Laser glass window

Solar Cell/ Photo voltaic conversion

- A solar cell is a solid state electrical device which converts energy of light directly in to electrical energy by the photo voltaic effect.
- Following are the different types of solar cell.

i) Mono-crystalline Silicon solar cell

ii) Poly-crystalline Silicon solar cell

iii) Thin film solar cell

Mono-crystalline Silicon solar cell

Mono-crystalline solar cells are made out of silicon ingots, which are cylindrical in shape.

Advantages:

- Highest efficiency(15-20%).
- Space-efficient. They require the least amount of space compared to any other types.
- Monocrystalline solar panels live the longest. Most solar panel manufacturers put a 25-year warranty on their monocrystalline solar panels.
- Tend to perform better than similarly rated polycrystalline solar panels at low-light conditions.

Disadvantages

- Monocrystalline solar panels are the most expensive
- If the solar panel is partially covered with shade, dirt or snow, the entire circuit can break down.

Poly-crystalline Silicon solar cell

- It consist of various crystalline sizes of silicon
- Raw silicon is used to make poly-crystalline silicon solar cell.

Advantages:

- Low amount of waste
- Reduced cost
- Respond to heat change is low

Disadvantages

- Low efficiency (13-16%)
- Lower space efficiency(required more space)
- Non- uniform look

Thin solar cell

- Thin film solar cells are manufactured by depositing one or more thin layers of photovoltaic material onto a substrate like glass plate, plastic, stainless steel etc.

Advantages:

- Mass production is simple
- Good looking
- Flexible making
- Low heat tolerance

Disadvantages

- Low efficiency (7-13%)
- Requires large space
- High Degradation rate.

Thin film solar cells are classified as

i) Amorphous silicon solar cell

ii) Gallium Arsenide solar cell

iii) Cadmium Sulphide solar cell

iv) Organic solar cell

Amorphous silicon solar cell

- Amorphous silicon is made by depositing thin layers of silicon on substrate like glass.
- Least amount of silicon (about 1%) is required to make amorphous silicon solar cell

Advantages:

- Flexible in making
- Light weight
- Working under poor light condition

Disadvantages

- Low efficiency (7-13%)
- .degrade fastly

EE206-Material Science

MODULE-VI

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SYLLABUS

Optical microscopy- Electron microscopy- Photoelectron spectroscopy- Atomic absorption spectroscopy- Introduction to Biomaterials & nanomaterials

Microscopy

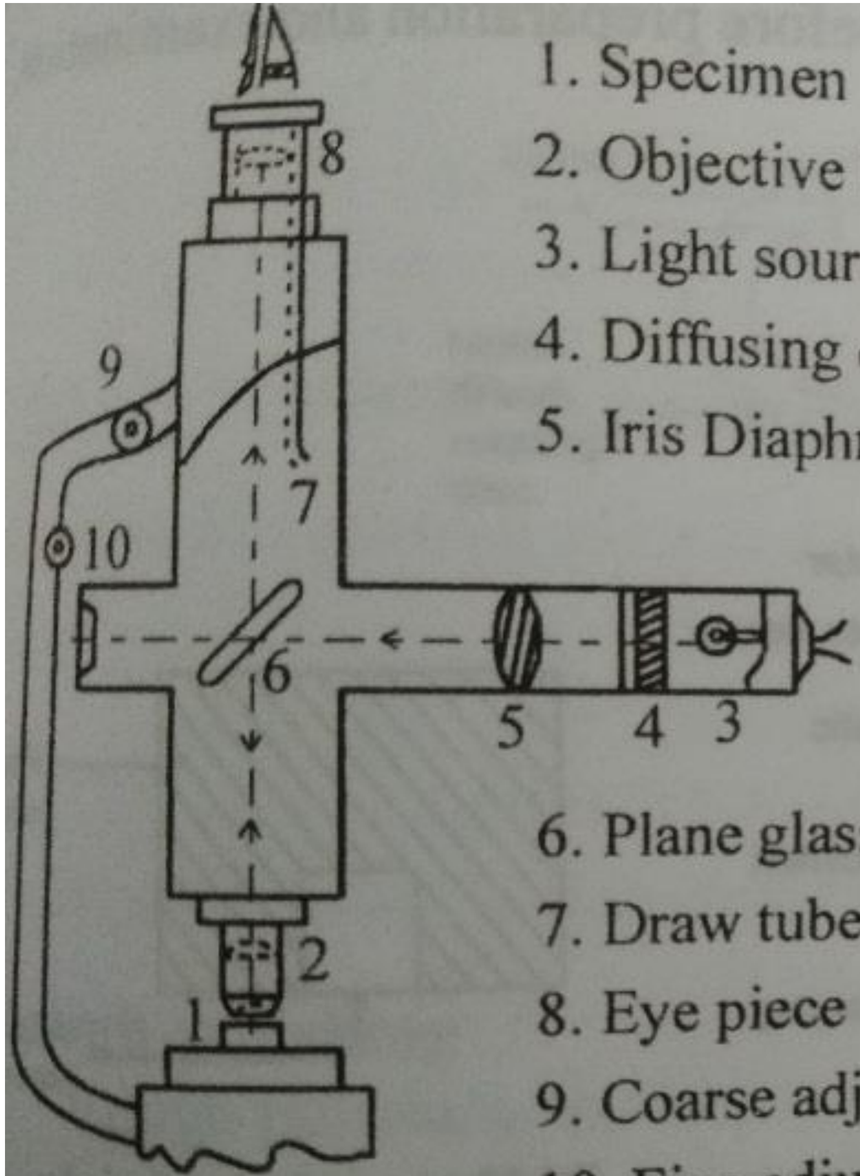
- It is the technical field of using microscopes to view objects and areas of objects that cannot be seen with the naked eye (objects that are not within the resolution range of the normal eye). There are three well-known branches of microscopy: optical, electron, and scanning probe microscopy.

- Optical or light microscopy involves passing visible light transmitted through or reflected from the sample through a single or multiple lenses to allow a magnified view of the sample.The resulting image can be detected directly by the eye, imaged on a photographic plate or captured digitally. The single lens with its attachments, or the system of lenses and imaging equipment, along with the appropriate lighting equipment, sample stage and support, makes up the basic light microscope.

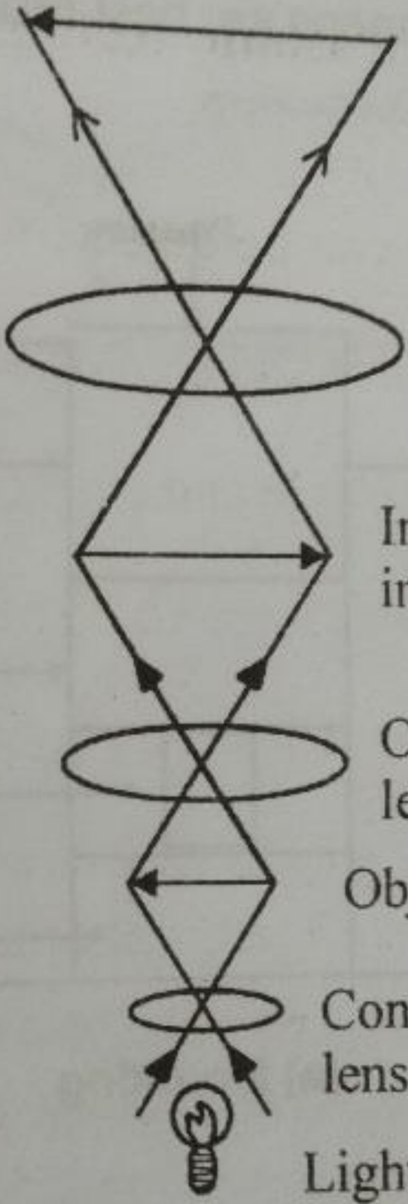
- Optical & electron microscopy involve the diffraction, reflection, or refraction of electromagnetic radiation/electron beams interacting with the specimen, and the collection of the scattered radiation or another signal in order to create an image

Optical microscopy

- It is a type of microscope which uses visible light and a system of lenses to magnify images of small samples.



1. Specimen
2. Objective lens
3. Light source
4. Diffusing disc
5. Iris Diaphragm
6. Plane glass reflector
7. Draw tube
8. Eye piece
9. Coarse adjustment
10. Fine adjustment



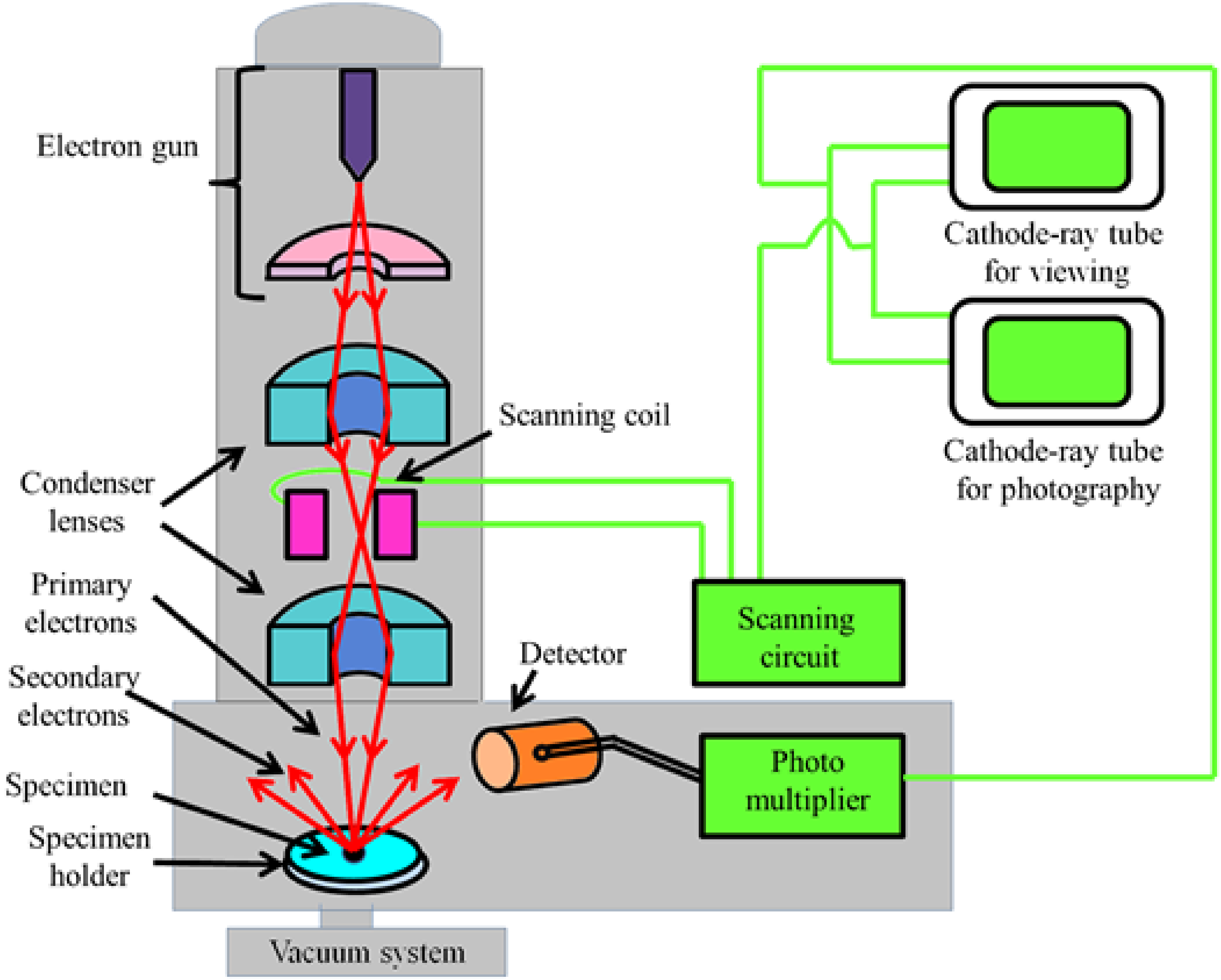
- Here source of light is kept inside the microscope tube itself and this light is diffused with the help of diffusing disc.
- The width of light beam is controlled by iris diaphra.
- The incident light strikes the plane glass reflector kept at 45° and is partially reflected down on the specimen.
- This rays of light get returned by reflection from specimen, pass through objective lens & glass reflector to form final image which can be seen through eye piece.
- A photographic camera may be mounted above eye piece inorder to record the metallographic structure of specimen.

Electron microscopy

- It is a type of microscope that uses a beam of electrons to create an image of specimen. It is used for obtaining high resolution images of living and non-living specimen, which is helpful in studying of detailed structure of tissues, cells etc.
- There are two basic models of the electron microscopes: *Scanning electron microscopes* (SEM) and *transmission electron microscopes* (TEM). In a SEM, the secondary electrons produced by the specimen are detected to generate an image that contains topological features of the specimen. The image in a TEM, on the other hand, is generated by the electrons that have transmitted through a thin specimen. Let us see how these two microscopes work and what kind of information they can provide:

Scanning electron microscope(SEM)

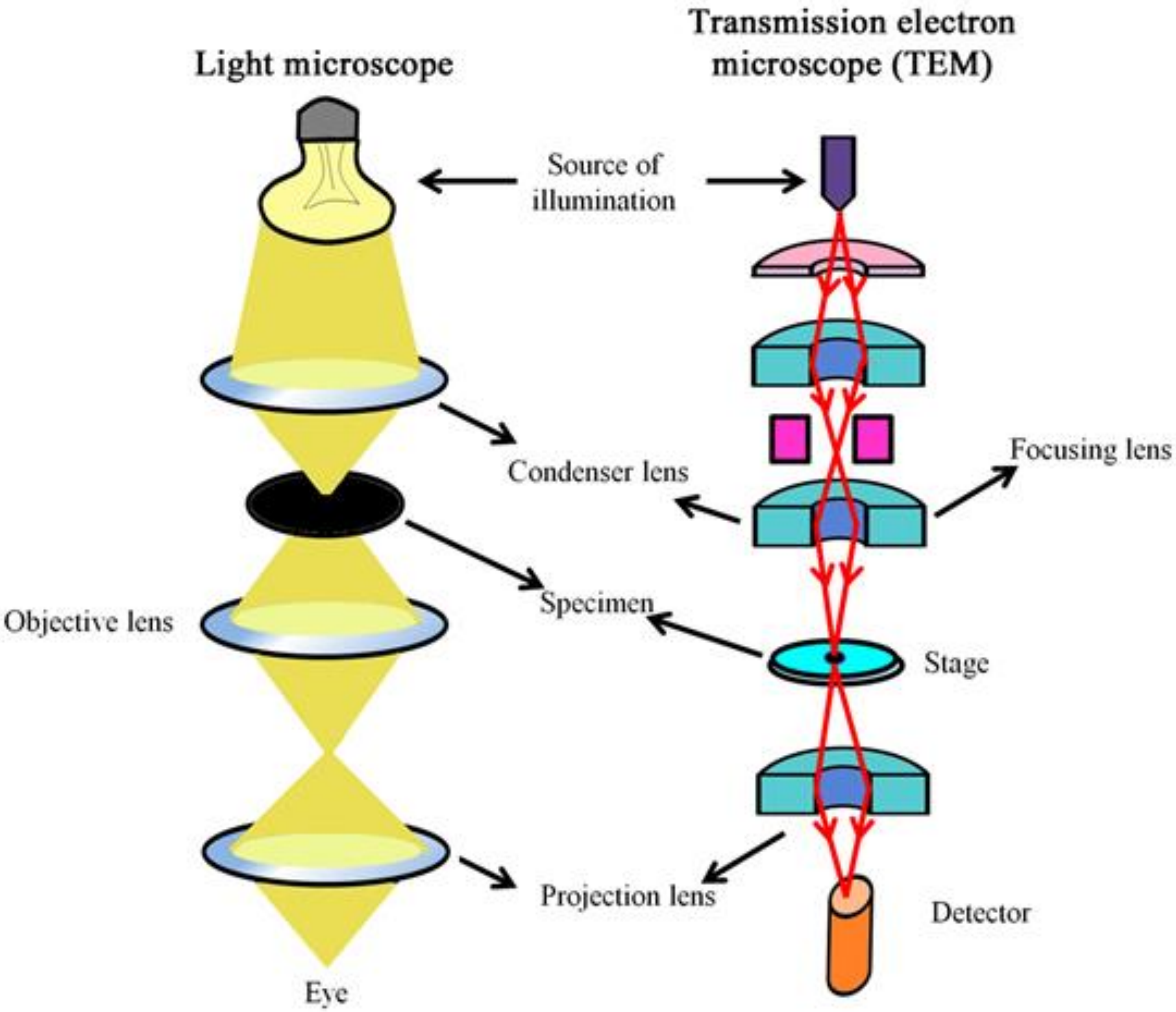
- Figure 5.2 shows a simplified schematic diagram of a SEM. The electrons produced by the electron gun are guided and focused by the magnetic lenses on the specimen.


Electron gun
Scanning coil
Condenser lenses
Primary electrons
Secondary electrons
Specimen
Specimen holder
Vacuum system
Detector
Scanning circuit
Photo multiplier
Cathode-ray tube for viewing
Cathode-ray tube for photography

- The focused beam of electrons is then scanned across the surface in a raster fashion. This scanning is achieved by moving the electron beam across the specimen surface by using deflection/scanning coils. The number of secondary electrons produced by the specimen at each scanned point are plotted to give a two dimensional image. In principle, any of the signals generated at the specimen surface can be detected. Most electron microscopes have the detectors for the secondary electrons and the backscattered electrons A secondary electron detector is biased with positive potential to attract the low energy secondary electrons. Detector for backscattered electrons is not biased; the high energy backscattered electrons strike the unbiased detector. As backscattered electrons come from a significant depth within the sample, they do not provide much information about the specimen topology. However, backscattered electrons can provide useful information about the composition of the sample; materials with higher atomic number produce brighter images.

Transmission electron microscope(TEM)

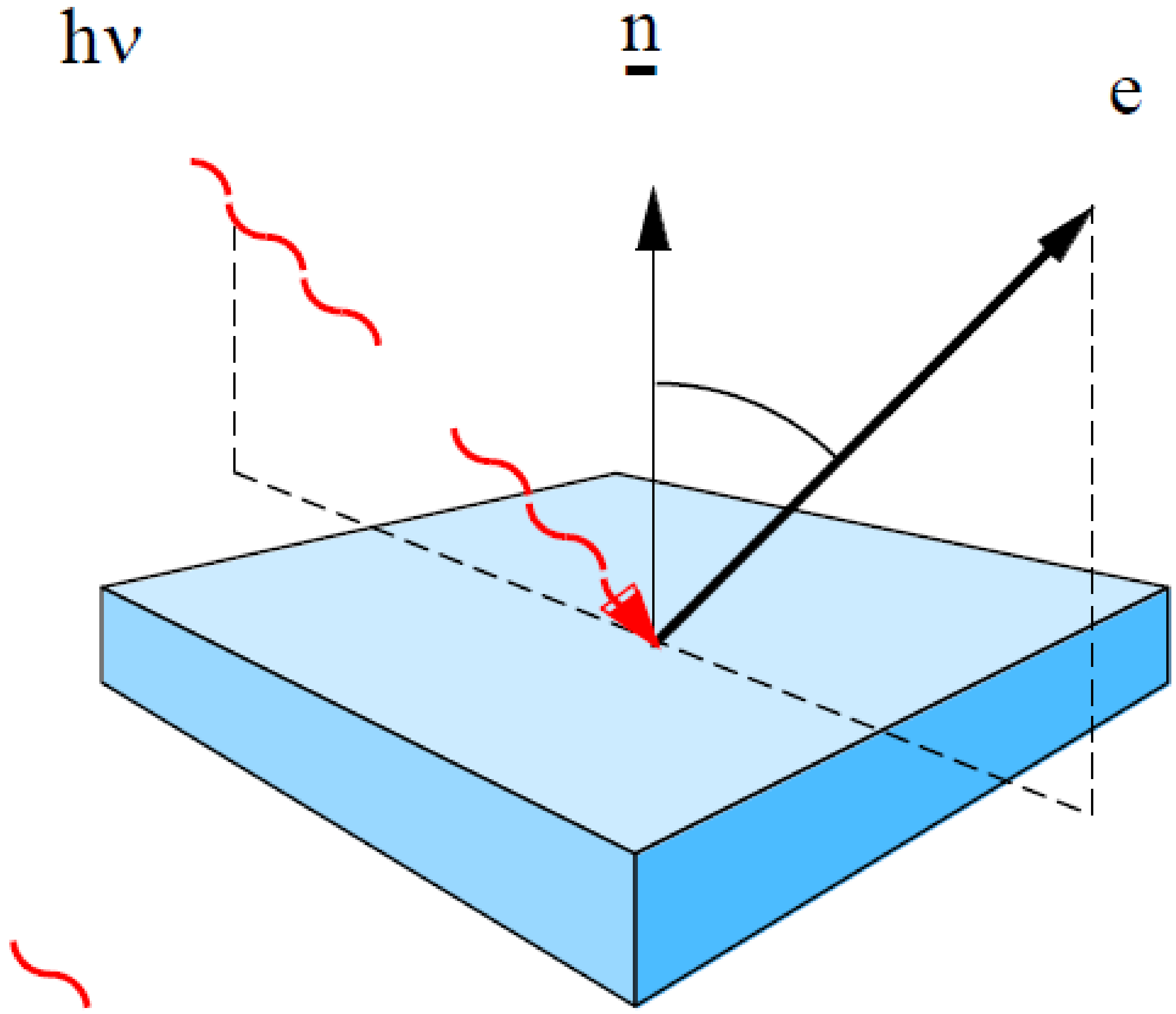
- The first electron microscope was developed by Knoll and Ruska in 1930s. It was a transmission electron microscope; the electrons were focused on a thin specimen and the electrons transmitted through the specimen were detected. Figure 5.3 shows a simplified optical diagram comparing a light microscope with a transmission electron microscope.


Light microscope
Transmission electron microscope (TEM)
Source of illumination
Condenser lens
Focusing lens
Specimen
Objective lens
Stage
Projection lens
Detector
Eye

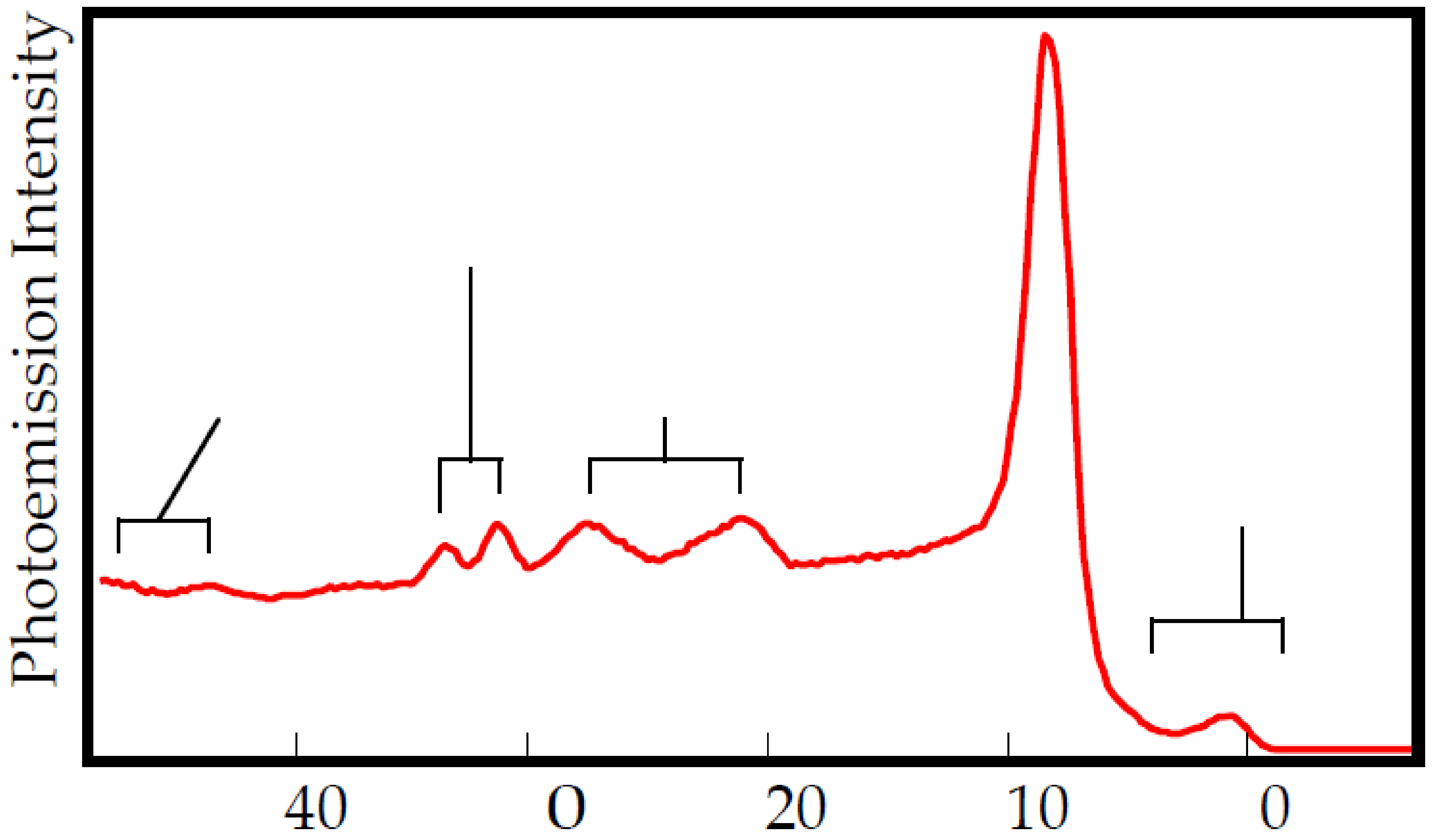
- Transmission electron microscopes usually have thermionic emission guns and electrons are accelerated anywhere between 40 – 200 kV potential. However, TEM with >1000 kV acceleration potentials have been developed for obtaining higher resolutions. Owing to their brightness and very fine electron beams, field emission guns are becoming more popular as the electron guns.

Photoelectron Spectroscopy

- In the photoelectric effect, first explained by Einstein in 1905, a photon of light ejects an electron from the surface of a sample. When the photon is absorbed by an electron, the kinetic energy of the electron is increased by an amount equal to the photon energy (by the conservation of energy). Some electrons will travel deeper into the sample, but some may head towards the surface. Providing that an electron is energetic enough to overcome the work function (Φ) of the sample (typically a few electron-volts), then it will leave the surface and can be detected.


hν
n
e

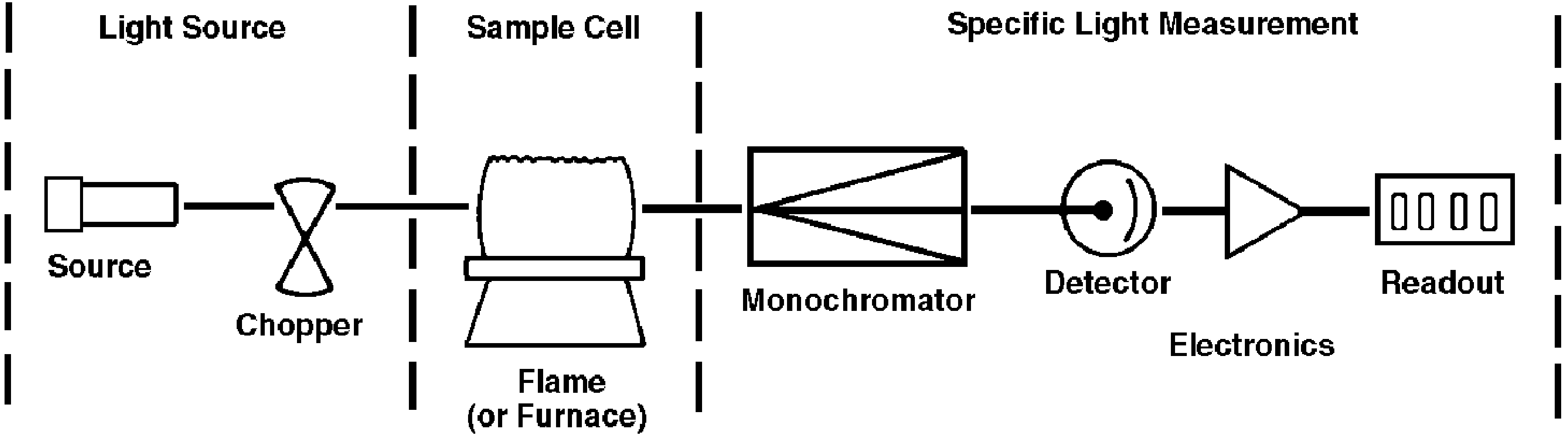
- By absorbing a photon, an electron is kicked from a low energy state (○) inside an atom into a higher energy state (•) in which it is free to move through the sample. Some of the photoelectrons energy is used to free the electron from its parent atom (the binding energy), and some is used to overcome the workfunction. Whatever is left is measured as the kinetic energy of the photoelectron. Thus if we measure the kinetic energy of an electron, and we know the photon energy ($h\nu$) and the workfunction (Φ) of the sample, then we can calculate the binding energy of the electron.


Photoemission Intensity
40
0
20
10
0

- The photoelectron spectra are often displayed as graphs of numbers of photoelectrons emitted per second (the photocurrent) plotted against kinetic energy or binding energy (above). In this spectrum peaks are seen which correspond to electronic energy levels in atoms of tungsten and gadolinium. A binding energy scale has been used, so that zero corresponds to the most energetic electrons in the sample (the valence electrons in the outer electron shells of the atoms) and larger binding energies correspond to electrons more tightly bound to their parent atoms.

Atomic absorption spectroscopy

- In atomic absorption, these functional areas are implemented by the components illustrated in Figure below. A light source which emits the sharp atomic lines of the element to be determined is required. The most widely used source is the hollow cathode lamp.



- It is also required that the source radiation be modulated (switched on and off rapidly) to provide a means of selectively amplifying light emitted from the source lamp and ignoring emission from the sample cell. Source modulation can be accomplished with a rotating chopper located between the source and the sample cell, or by pulsing the power to the source. Special considerations are also required for a sample cell for atomic absorption.
- An atomic vapor must be generated in the light beam from the source. This is generally accomplished by introducing the sample into a burner system or electrically heated furnace aligned in the optical path of the spectrophotometer. Several components are required for specific light measurement. A monochromator is used to disperse the various wavelengths of light which are emitted from the source and to isolate the particular line of interest.

- The wavelength of light which is isolated by the monochromator is directed onto the detector, which serves as the ‘‘eye’’ of the instrument. This is normally a photomultiplier tube, which produces an electrical current dependent on the light intensity. The electrical current from the photomultiplier is then amplified and processed by the instrument electronics to produce a signal which is a measure of the light attenuation occurring in the sample cell. This signal can be further processed to produce an instrument readout directly in concentration units.

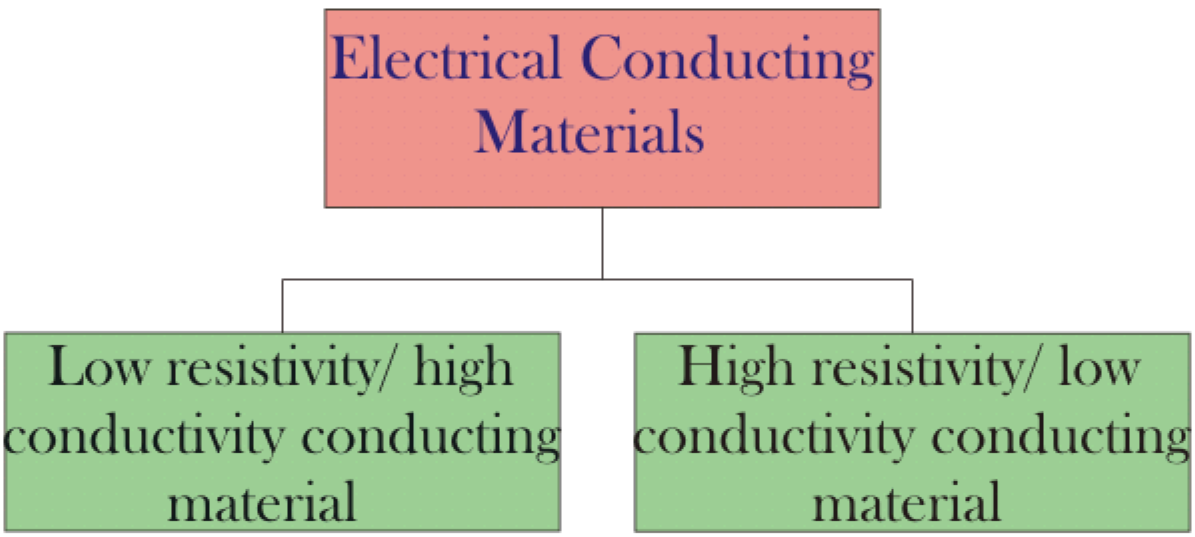
Classification of Electrical Conducting Materials

Electrical conducting material are the basic requirement for electrical engineering products. The electrical conducting material can be classified as below-

Based on Resistivity or Conductivity

- Low resistivity or high conductivity conducting material
- High resistivity or Low conductivity conducting material

A classification chart of conducting materials based on resistivity or conductivity is shown in figure below-



Low Resistivity or High Conductivity Conducting Material

Material having low resistivity or high conductivity are very useful in electrical engineering products. These material used as conductors for all kind of windings required in electrical machines, apparatus and devices. These material are also used as conductor in transmission and distribution of electrical energy.

Some of low resistivity or high conductivity materials and their resistivity are given in table below –

- Silver
- Copper
- Gold
- Aluminum

High Resistivity or Low Conductivity Conducting Material

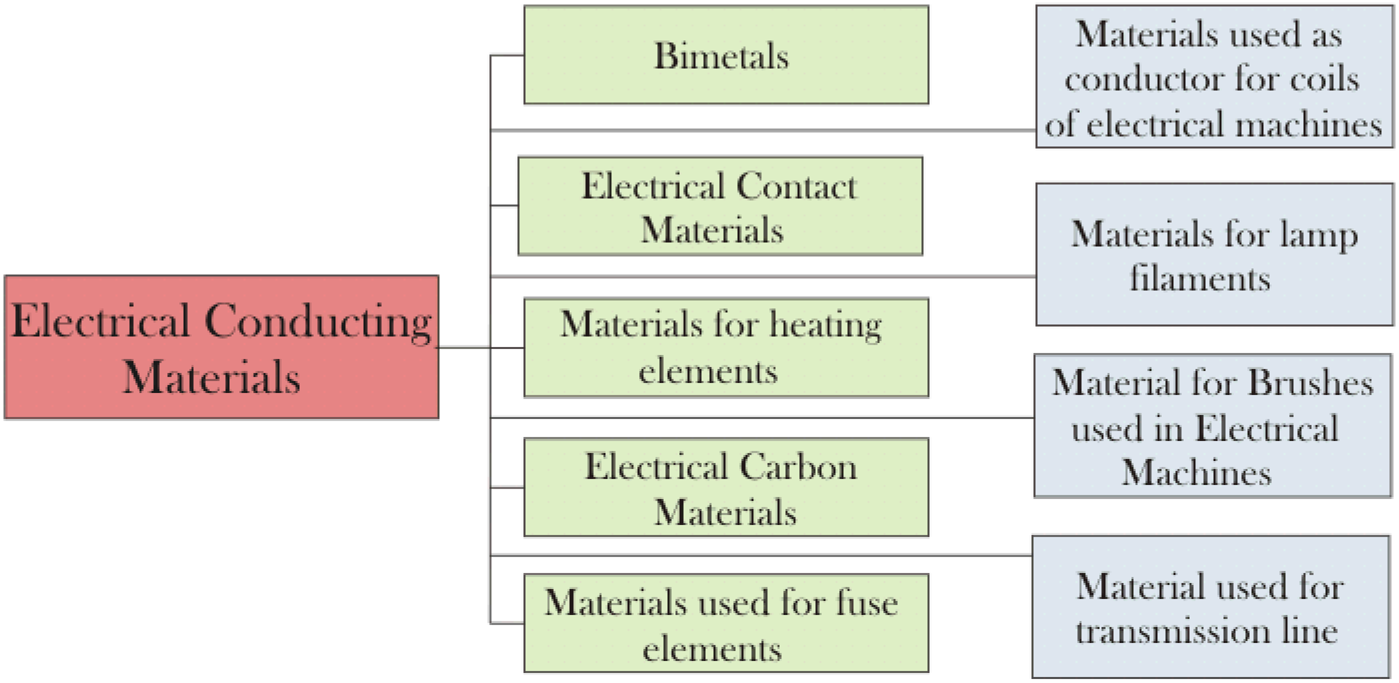
Materials having High resistivity or Low conductivity conducting are very useful for electrical engineering products. These material are used to manufacture the filaments for incandescent lamp, heating elements for electric heaters, space heaters and electric irons etc.
Some of materials having High resistivity or Low conductivity are listed below:

- Tungsten
- Carbon
- Nichrome or Brightray – B
- Nichrome – Vor Brightray – C
- Manganin

Based on Area of Application

- Materials used as conductor for coils of electrical machines
- Materials for heating elements
- Materials for lamp filaments
- Material used for transmission line
- Bimetals
- Electrical Contact Materials
- Electrical Carbon Materials
- Material for Brushes used in Electrical Machines
- Materials used for fuses

A classification chart of conducting materials based on their applications is shown in figure below-



Materials Used as Conductor for Coils of Electrical Machines

Materials having low resistivity or high conductivity such as copper, silver and aluminum can be used for making coils for electrical machines. However, looking to optimum conductivity, mechanical strength and cost, copper is much suitable for making coils for electrical machines.

Materials for Heating Elements

Materials having high resistivity or low conductivity such as Nichrome, Kanthal, Cupronickel and Platinum etc. are used for making heating elements. Materials used for heating elements must possess following properties-

- High melting point
- Free from oxidation in operating atmosphere
- High tensile strength
- Sufficient ductility to draw the metal or alloy in the form of wire

Materials for Lamp Filaments

Materials having high resistivity or low conductivity such as Carbon, Tantalum and Tungsten etc. are used for making incandescent lamp filament. Materials used for making incandescent lamp filament must possess following properties-

- High melting point
- Low vapour pressure
- Free from oxidation in inert gas (argon, nitrogen etc.) medium at operating temperature
- High resistivity
- Low thermal coefficient of expansion
- Low temperature coefficient of resistance
- Should have high young modulus and tensile strength
- Sufficient ductility so that can be drawn in the form of very thin wire
- Ability to be converted in the shape of filament
- High fatigue resistance against thermally induced fluctuating stresses
- Cost should minimum

Material Used for Transmission Line

Materials used for making conductor for transmission line must possess following properties –

- High conductivity
- High tensile strength
- Light weight
- High resistance to corrosion
- High thermal stability
- Low coefficient of thermal expansion
- Low cost

Materials use for transmission lines are listed below-

- Copper
- Aluminum
- Cadmium-Copper alloys
- Phosphor bronze
- Galvanized steel

- Steel core copper
- Steel core aluminum

Bimetals

Many combinations of metals with different "Coefficient of linear thermal expansion" can be used to form the bimetals. Some of the commonly used combinations for making bimetallic strips are listed below-

- Iron, nickel, constantan (high "Coefficient of linear thermal expansion")
- Alloy of iron and nickel (low "Coefficient of linear thermal expansion")

Electrical Contact Materials

The successful operation of electrical contacts is function of various factors. While selecting a suitable material for electrical contact, we have to consider the factors. Some of most important factors of these are listed below –

- Contact resistance
- Contact force
- Voltage and current

Electrical Carbon Materials

Carbon in widely used in electrical engineering. Electrical carbon materials are manufactured from graphite and other forms of carbon.
Carbon is having following applications in electrical Engineering–

- For making filament of incandescent lamp
- For making electrical contacts
- For making resistors
- For making brushes for electrical machines such as DC machines, alternators.
- For making battery cell elements
- Carbon electrodes for electric furnaces
- Arc lighting and welding electrodes
- Component for vacuum valves and tubes
- For makings parts for telecommunication equipment's

Material for Brushes Used in Electrical Machines

Before selecting the material for brushes, we should keep in our mind following requirements in a brush –

- Contact resistance
- Thermal stability
- Lubrication properties
- Mechanical strength
- Low brittleness

Material used for Brushes in electrical machines are listed below-

- Carbon
- Natural graphite
- Electro graphite
- Metal graphite
- Copper

Materials Used for Fuse Elements

Fuse element is primary requirement of a fuse unit. The fuse element should have following properties-

Low resistance – to avoid the undesirable voltage drop across the fuse element, so that it should effects the normal functioning or performance of circuit or device or equipment

Low melting point – the fuse element must have low melting point. So that it blow out due to heating by excess current during over load or short circuit.

Different types of metals and alloys are used for fuse element. Some of these elements are listed below –

- Aluminum
- Lead and tin
- Copper
- Silver
- Rose' Alloys
- Wood alloys

MODULE – I

SYLLABUS

Conducting Materials: Conductivity- dependence on temperature and composition – Materials for electrical applications such as resistance, machines, solders etc.

Semiconductor Materials: Concept, materials and properties-– Basic ideas of Compound semiconductors, amorphous and organic semiconductors- applications.

Dielectrics: Introduction to Dielectric polarization and classification –Clausius Mosotti relation- Behavior of dielectric in static and alternating fields.

1.1 Conductance(G):-

It is the properties of a material by which it allows flow of electric current.

$$G = 1/R = \frac{1}{\rho * (\frac{l}{a})} = \frac{a}{\rho * l}$$

1.2 Conductivity or Specific Conductance (k):-

It is the conductance of a material having unit length and unit cross section.

$$G = 1/R = \frac{1}{\rho * (\frac{l}{a})} = \frac{1}{\rho * (\frac{1}{1})} = \frac{1}{\rho} = k$$

Ie. $K = \frac{1}{\rho}$

1.3 Conductivity – Dependence On Temperature & Composition:-

→ The effect of high temperature decreases the conductivity of a metal. The effect of high temperature varies cubically at low temperature & linearly at high temperature.

→ Composition means forming alloys (example " nichrome") or adding impurities to pure metal.

→ Composition decreases the conductivity.

1.4 Classification of conducting material:

Conducting materials are broadly classified in to two

(i) Low resistivity material (Silver, Copper, Gold, Aluminium, Zinc, Nickel, Cadmium, Iron, etc)

(ii) High resistivity material (Tungsten, Nichrome, carbon, Mangenese, Platinum, Constantan etc)

1.5 Properties of Low resistivity material:-

(i) Low resistance-temperature coefficient:-

This means that the change of resistance with change in temperature should be low. If resistance is increased with temperature, the power loss and voltage drop is increased. To avoid this situation ensure materials are low resistance-temperature coefficient.

(ii) Sufficient mechanical strength:-

Mechanical stresses are produced in overhead line conductors used for transmission and distribution of electrical power due to wind and their own weight. Mechanical stresses are also produced in conducting materials used for winding of generators, motors, and transformers when loaded. Therefore, to withstand the mechanical stresses in such applications, the conducting material should possess sufficient mechanical strength.

(iii) Ductility:-

Different sizes and shapes of conductors are required for different applications. To fulfill this requirement the conducting material should posses high ductility.

(iv) Solderability:-

Solderability should be high with minimum contact resistance during joining.

(v) Resistance to corrosion:-

It is not easily corroded or rusted when used without insulation in outdoor atmosphere.

1.6 <u>Properties of High resistivity material:-</u>

(i) Low resistance-temperature coefficient:-

This means that the change of resistance with change in temperature should be low. If resistance is increased with temperature, the power loss and voltage drop is increased. To avoid this situation ensure materials are low resistance-temperature coefficient.

(ii) High Melting Point:-

It should have ability to withstand high temperature for long time without melting.

(iii) No tendency for Oxidation:-

It should not have no tendency to oxidize at high temperature. If an oxide layer is formed on heating element, the amount of heat radiation is reduced.

(iv) It should have high mechanical strength so that if it is drawn into thin wires it may not break.

(v) Ductility:-

It can be drawn into any shape and size easily.

1.7 Low Resistivity Materials:-

(i) **Copper :-** Copper is a crystalline, non-ferrous, diamagnetic , reddish colored metal.

Advantages:- → Highly conductive material, low cost & resistivity is (28 * 10^-9)

Properties:- → Due to high ductility (about 55%), Suitable for making thin wires.

→ Due to high melting point (1083˚C), suitable for use at high temperature.

→ High tensile strength (300-350MPa) provide more strength towards mechanical loads.

Applications:- → Annealed Copper is used as power cables, winding wires for electrical machines.

→ Hard drawn copper is suitable for overhead transmission lines, bus-bars etc.

(ii) **Aluminium :-** Aluminium is a crystalline, non-ferrous, paramagnetic , white colored metal.

Advantages:- → conductive is lower than copper (about 75% less) , light weight &low cost material.

Properties:- → Due to high ductility (about 50%), Suitable for making cables, strands & conductors

→ Due to low tensile strength (50-70 MPa), not suitable for making windings of electrical machines.

1.8 High Resistivity Materials:-

(i) Tungsten:-

- It is used in incandescent lamp as filament due to high melting point (3300°C).
- It has very high tensile strength in its thinnest form.
- It does not brittle at high temperature.

(ii) Nichrome:-

- It is an alloy of [Mn(1.5%), Ni(75-78%), Cr(20-23%)]
- It is used for making heating elements of electric heaters, electric ovens, room heaters, electric furnaces etc.
- It has good mechanical strength and desirable thermal properties

(iii) Manganin:-

- It is an alloy of [Cu(86%), Mn(12%), Ni(2%)]

- It can easily drawn into thin wires
- It is used in making resistance boxes, resistors for precision instruments, shunts for electrical measuring instruments etc.

(iv) Constantan:-

- It is an alloy of [Cu(60%), Ni(40%)]
- It is used for making loading rheostats, starters for electrical motors, field winding for generatorsetc.

1.9 Materials for Electrical Applications:-

- Carbon is used for making brushes of electrical machines.
- Brass is used for making slip rings of alternator.
- Lead- Tin mixture [37% lead – 63% Tin] is used for making fuses.
- Lead- Tin mixture [50% lead – 50% Tin] is used for making solders.

Questions for University Exam

1. What do you understand by the term conductivity? Mention the factors which affect the value of conductivity?
2. Explain why conducting materials like copper and aluminum are not used for making elements of electrical heaters.

   Copper and aluminum are low resistive material. If they are used for making elements of heaters, overall size of equipment increases. Also electrical heaters requires high resistive material.
3. What material is used for elements of electrical heaters?. What are the properties the material must possess for this reason?

   Platinum, Nichrome, Manganin, Constantan

   It should possess the properties like high melting point, high resistance, good mechanical strength, free from oxidation, able to withstand corrosion
4. Why copper is preferred to as a material for winding of electrical machines as compared to aluminium?

   Copper has high tensile strength and low resistance than aluminum. That is why copper is preferred to as a material for winding of electrical machines as compared to aluminum
5. Explain clearly electrical, mechanical and other reasons for using Aluminium for overhead transmission lines?

Aluminum is low cost, soft light weight than copper. It produces less sag.

ACSR (Aluminium Conductor Steel Reinforced) material is commonly used for over head transmission line. In which steel helps to prevent electrolytic corrosion, mechanical stress etc. and Aluminium carriers bulk of current

6. A copper wire and aluminium wire has same length and resistance. If same current is passes through both wires which will attain high temperature rise. Give reason?

   Temperature rise is inversely proportional to surface area of conductor. Since surface area of Copper is 1.5 times lesser than aluminium. Therefore copper will attain high temperature.

7. What are the advantages of copper over aluminum?
   - Its conductivity is high
   - It has high tensile strength
   - It has low resistivity
   - It can be easily soldered and weldered
   - It has good mechanical strength
   - It is highly resistant to corrosion

8. What are the advantages of aluminum over copper?
   - Low cost
   - Soft metal
   - Much lighter than copper
   - It does not react with rubber. Therefore suitable with rubber insulation

1.10 Semiconductors:-

Semi conductor is a solid crystalline material whose conductivity is between conductor and insulator. A semiconductor has four electrons in the valance ring while the best insulator has eight electrons in the valance ring and the best conductor has only one electron in the valance ring.On the basis of band theory semiconductors differ from conductors and insulators that they have narrow forbidden gap. Typical semiconductor materials are Germanium and Silicon and each has four valence electrons in the outer orbit.

Semiconductors are classified in to two

(i) Intrinsic semiconductors

(ii) Extrinsic semiconductors

1.10.1 Intrinsic semiconductors:-

Silicon and germanium with Pure semiconducting state is called intrinsic semiconductors.

1.10.2 Extrinsic semiconductors:-

Extrinsic semiconductors are those in which impurities are doped into intrinsic semi conductors to improve conducting property. Extrinsic semiconductors are classified in to two (i) N-type Semi conducting material, (ii) P-type semiconducting material.

1.10.3 N-type Semi conducting material:-

When a pentavalent impurity like Antimony, Arsenic, Phosphorous is added to an intrinsic semiconductor, only four of its valance electrons lock into the covalent bond. The fifth valance electron of the impurity atom is free to move through the crystal. This electron creates conduction. Since in N-type semiconductors, electrons are majority carriers.

1.10.4 P-type Semi conducting material:-

When a trivalent impurity like Galium, Indium is added to an intrinsic semiconductor, they lock into crystal structure.. Here a hole is created by deficiency of an electron in the covalent bond. Since in P-type semiconductors, electrons are majority carriers.

1.11 Properties of Semiconducting Materials:-

- Small size, light weight
- They consumes less power
- It shows large efficiency
- They are almost shock proof
- Resistance of semiconductor decreases non linearly with rise in temperature
- Presence of impurity increases conducting property largely.

1.12 Applications of Semiconducting Materials:-

- Rectifiers
- Photovoltaic cells
- Varistors
- Transistors
- Hall effect transducers
- Strain gauges
- Integrated circuits (IC's)

- Measuring instruments like flux meter, galvanometer, compass modulator etc.

1.13 Compound Semiconductors:-

- Compound semiconductors are produced by combining equal atomic fractions of elements of III & V columns, or II & VI columns.
- Their structures are of cubic type.

III	V	compound
B, Al, Ga, Ib	N, P, As, Sb	GaAs, InSb

II	IV	compound
Cd, Zn	S, Te, Se	CdS, ZnSe

Properties:- High frequency, high power, flexible design

GaAs → LED, High frequency FET's for mobile communications

InSb → Infra Red light detectors

CdS → Visible light meters

→ Compound semiconductors are used in diodes, transistors, SCR, solar cell etc.

1.14 Amorphous semiconductors:-

- Polymers can be doped to make them into useful semiconductors are called amorphous semiconductors.
- It can be classified as (i) elemental amorphous, (ii) covalent amorphous & (iii) ionic amorphous
- Properties:- 1. Suitable for switching applications, 2. Easy to fabricate
- Applications:- 1.used in inexpensive photo voltaic cell, 2. Used in xerography

  Poly Phenylene Vinylidene (PPV):- used in LED emitting layer
- Anthracene, pentacene :- FET's

- In 2000, Nobel prize in chemistry goes to Alan Heeger, Alan Mac Diarmid & Hideki Sharakawa for introducing of amorphous semiconductors.

1.15 Organic Semiconductors:-

Organic semiconductors are solids whose building blocks are pi bonded molecules or polymers made up by carbon and hydrogen atoms and – at times – heteroatoms such nitrogen, sulfur and oxygen. They exist in form of molecular crystals or amorphous thin films. In general, they are insulators but become semiconducting when charges are either injected from appropriate electrodes, upon doping or by photo excitation.

Advantages:- Less expensive

Applications:- organic LED, organic FET, Organic solar cells

Questions for University Exam

9. Distinguish between Intrinsic and Extrinsic semiconductors?
10. Discuss briefly the attractive features of organic semiconductors and its applications?
11. Compare Silicon, Germanium and Gallium-arsenide with reference to their semiconducting properties?
12. Discuss briefly the attractive features of compound semiconductors and its applications?

1.16 Polarization:-

→Polarization can be define as the definite orientation of electrostatic dipoles in a dielectric material due to an applied electric field

→Electric field applied to an atom causes movement of the electrons opposite to that of the field. This movement is opposed by the attractive force between nuclei & electrons. The resultant effect is to separate the +ve & -ve charges in each molecule. This effect is called polarization.

1.17 Electronic Polarization:-

→The displacement of the centre of the –vely charged electron cloud relative to the +ve nucleus of an atom by the electric field results electronic polarization. This shifting of electron cloud results in a dipole moment. Dipole moment is define as the product of the charge and the shift distance

$$P = qd$$

Also polarization P is proportional to the field strength E,

$$P_e = \alpha_e E$$

Where α_e is the proportionality constant & is define s the electronic polarizability and is independent of temperature

→ Mono atomic gas exhibits this type of polarization. In case of mono atomic gas it is found that electronic polarizability is given by

$$\alpha e = 4\pi\varepsilon 0R^3$$

1.18 Ionic Polarization:-

→ In an ionic molecule, displacement of cations & anions in opposite direction under the action of external electric field causes polarization called ionic Polarization. Ionic polarization P is proportional to the field strength E is expressed as,

$$Pi = \alpha i\ E$$

Where αi is the proportionality constant & is define s the ionic polarizability and is independent of temperature.

1.19 Dipolar or Orientation Polarization:-

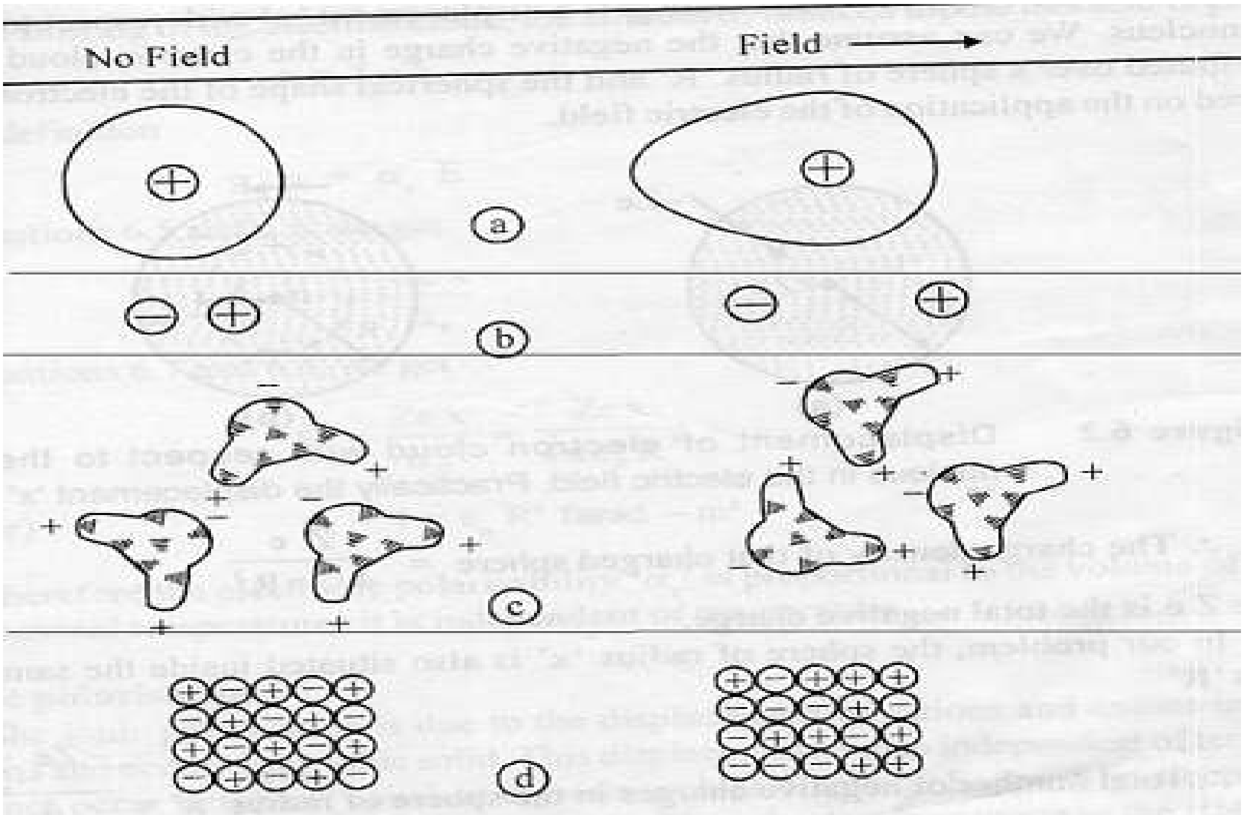
→ Polarization due to the rotation (orientation) of the molecule of a polar dielectric having constant dipole moment in the direction of an electric field is called dipolar polarization.

→ When an electric field is applied on a permanent dipole moment molecule, then the dipole tends to align themselves in the direction of applied field induces orientation polarization, which is given by

$$Po = \alpha oE$$

Where $\alpha o = m^2/3kBT$

→ Orientation polarization is inversely proportional to temperature & proportional to square of the permanent dipole moment.



Different types of polarisation mechanisms
a. Electronic Polarisation b. Ionic Polarisation
c. Orientational Polarisation d. Space charge Polarisation

1.20 Clausius-Mosotti Relation:-

Consider the elements like Ge, Si etc. which have cubic structures. Since there are no ions and permanent dipoles in these material .ie $\alpha i = \alpha o = 0$

Substituting the Lorentz form for local field 'Ei', we get

$$P = N \alpha e \, Ei$$

$$P = N \alpha e \left[E + \frac{P}{3\varepsilon o} \right]$$ Where $Ei = E + \frac{P}{3\varepsilon o}$ (Lorentz electric field)

$$P = N \alpha e E + \frac{N \alpha e P}{3\varepsilon o}$$

$$P - \frac{N \alpha e P}{3\varepsilon o} = N \alpha e E$$

$$P \left(1 - \frac{N \alpha e}{3\varepsilon o}\right) = N \alpha e E$$

$$P = \frac{N \alpha e E}{1 - \frac{N \alpha e}{3\varepsilon o}} \quad \ldots\ldots(1)$$

We know that

$D = P + \varepsilon o E$

$P = D - \varepsilon o E$

$\frac{P}{E} = \frac{D}{E} - \varepsilon o = \varepsilon o\ \varepsilon r - \varepsilon o$ (Where $D = \varepsilon o\ \varepsilon r\ E$)

$P = (\varepsilon o\ \varepsilon r - \varepsilon o)E$ ……(2)

Compare eqn (1) and eqn (2), we get

$$(\varepsilon o\ \varepsilon r - \varepsilon o)E = \frac{N\ \alpha e\ E}{1 - \frac{N\ \alpha e}{3\varepsilon o}}$$

$$1 - \frac{N\ \alpha e}{3\varepsilon o} = \frac{N\ \alpha e\ E}{(\varepsilon o\ \varepsilon r - \varepsilon o)E}$$

$$1 = \frac{N\ \alpha e}{3\varepsilon o} + \frac{N\ \alpha e}{(\varepsilon o\ \varepsilon r - \varepsilon o)}$$

$$1 = \frac{N\ \alpha e}{3\varepsilon o} + \frac{3\ N\ \alpha e}{3\varepsilon o(\ \varepsilon r - 1)}$$

$$1 = \frac{N\ \alpha e}{3\varepsilon o}\left[1 + \frac{3}{(\ \varepsilon r - 1)}\right]$$

$$1 = \frac{N\ \alpha e}{3\varepsilon o}\left[\frac{\varepsilon r\ - 1 + 3}{\varepsilon r\ - 1}\right]$$

$$1 = \frac{N\ \alpha e}{3\varepsilon o}\left[\frac{\varepsilon r\ + 2}{\varepsilon r\ - 1}\right]$$

$$\frac{N\ \alpha e}{3\varepsilon o} = \frac{1}{\frac{\varepsilon r\ + 2}{\varepsilon r - 1}}$$

$$\boxed{\frac{N\ \alpha e}{3\varepsilon o} = \frac{(\varepsilon r - 1)}{(\varepsilon r\ + 2)}}$$

Where N = number of molecules per unit volume

$\varepsilon o = absolute\ permittivity$

$\varepsilon r = relative\ permittivity$

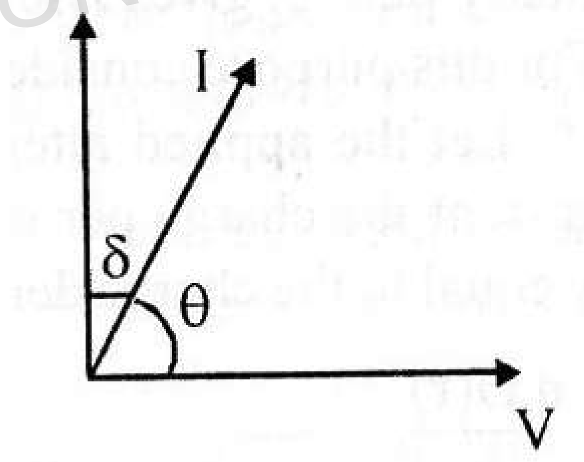
The above equation is known as clausius- Mosotti relation. This equation is very helpful to find electronic polarisability knowing the value of εr of the medium.

1.21 Dielectric Polarization under static field:-

→ A dielectric consist of molecules, the atomic nuclei of which are effectively fixed, relative to each other. In the absence of external field the electrons are distributed symmetrically round the nucleus at any instant. When a static electric field is applied, the electrons of atoms are acted upon by this field.. This causes movement of electrons, which is opposed by the attractive force between nuclei & electrons. The resultant effect is to separate the +ve & -ve charges in each molecule & induces polarization.

1.21 Dielectric Polarization under alternating field:-

- When an alternating field is applied to dielectric material, the position of atoms or molecules are disturbed. Also electrical energy is absorbed by the dielectric material and is dissipated in the form of heat (called dielectric loss). When ac voltage is applied to a dielectric, an angle $\delta = 90-\theta$ (called loss angle) develops and it is helpful in the analysis of power dissipation.



Questions for University Exam

13. What is electric dipole moment

    Two equal and opposite charge (+q & -q) are separated by a distance(d) is called electric dipole moment. Ie

    $$m = q*d$$

14. What are Dielectrics

Dielectrics are the material having electric dipole moment permanently or temporarily by applying the electric field.

15. Explain important properties associated with dielectrics

Ferro electricity: Property by which dielectric material exhibit electric polarization in the absence of applied electric field.

Piezo electricity: Property by which dielectric material exhibit electric polarization in the presence of mechanical pressure.

Pyro electricity: Property by which dielectric material exhibit electric polarization in the presence of thermal energy.

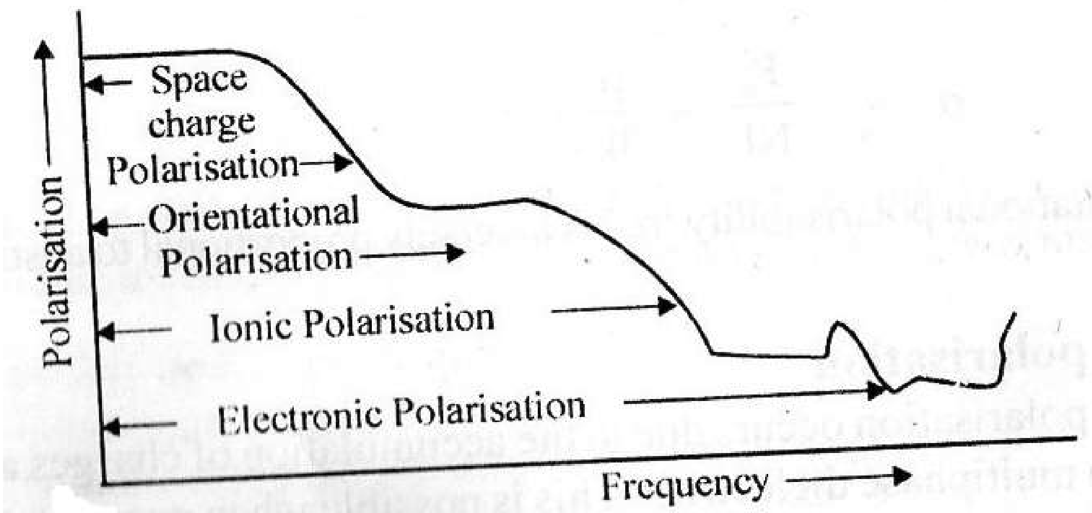
16. What is mean by Lorentz local field in a dielectric?

The local field in a dielectric is the space and time average of electric field acting on a molecule or atom of dielectric kept in an applied field. ie

$Ei = E + \frac{P}{3\varepsilon o}$ (Lorentz electric field)

17. What is the effect of frequency of ac electric field on polarization

As the frequency increases, total polarization decreases. At high frequencies, orientation polarization & space charge polarization does not occurs.



Electronic polarisation occurs at all frequencies. Ionic polarization does not occur at optical frequencies. Orientation polarization occurs at electrical frequencies. Space=charge polarization occurs only at power frequencies.

18. What is relaxation time, optical absorption, infrared absorption?

relaxation time: It is the time required by charges to reach normal position from disturbed position.

optical absorption: The dielectric losses in the optical region, associated with electrons are called as optical absorption

infrared absorption: The dielectric losses in the infrared region, associated with electrons are called as infrared absorption.

19. What is mean by local field in a dielectric and how it is calculated for a cubic structure? Deduce Clausius –Mosotti relation and explain its use in predicting the dielectric constant of solids?
20. Explain the different types of polarization in dielectrics and sketch their dependence on frequency of applied field?
21. Write short note on (i) ferro electricity (ii) piezo electric effect (iii) electric polarisation (iv) dielectric loss and (v) loss angle

………………………………………………………………………………….

CHAPTER – 3

SYLLABUS

Mechanism of breakdown in solids, liquids and gases – Dielectric Breakdown – Intrinsic breakdown – Electro mechanical breakdown – Townsends criterion – Streamer mechanism – suspended particle theory – ageing of insulators – Application and breakdown of vacuum insulation – treatment and testing of transformer oil

3.1 Breakdown in Gaseous dielectrics:-

- Breakdown in gases begins with ionization due to collision of electrons (intrinsic breakdown).
- Breakdown is accelerated by secondary emission of electrons from cathode (Townsends criterion).

3.2 Breakdown in Liquid dielectrics:-

Liquid dielectrics are sub classified into three. They are

1. Contaminated liquid dielectrics.
2. Technically pure liquid dielectrics.
3. Degassed high purity liquid dielectrics.

- In contaminated liquid dielectrics, breakdown occurs due to the formation of conducting bridges between the electrodes by droplets of emulsified water and suspended particles (**Suspended Particles Theory**).
- In technically pure liquid dielectrics, breakdown is initiated by ionization of gas contained in the liquid. Here gas will act as a conducting medium leading to breakdown.
- In degassed high purity liquid dielectrics, breakdown is evidently due to collision ionization (intrinsic breakdown).

3.3 Breakdown in Solid dielectrics:-

Three types of breakdown are possible in solid dielectric.

1. Electro thermal breakdown
2. Purely electrical breakdown
3. Electro mechanical breakdown.

3.4Electro thermal breakdown:-

It occurs due to heat produced by dielectric loss. If rate of generation of heat in electrons are greater than the heat dissipated in the surroundings, temperature of dielectric increases eventually, results breakdown.

3.5 Purely electrical breakdown:-

It occurs due to intrinsic breakdown.

3.6Electro mechanical breakdown :-

When an electric field is applied to a dielectric between the electrodes, a mechanical force will be exerted on dielectric. This will create force of attraction between the surface charges of dielectrics. This compression due to force of attraction decreases the insulation thickness, there by creates breakdown.

3.7 Dielectric Breakdown:-

- When a dielectric losses its insulation resistance and permits large current to flow throw it is called dielectric breakdown. Important types of dielectric breakdown are
  1. Intrinsic breakdown.
  2. Thermal breakdown.
  3. Electrochemical breakdown.
  4. Discharge breakdown.
  5. Defect breakdown.

3.8 Intrinsic Breakdown:-

- Intrinsic breakdown are of two types
  1. Electronic breakdown
  2. Avalanche or Streamer Breakdown

3.8.1 Electronic Breakdown:-

- When an electric field is applied to an atom, electrons gains energy from electric field and crosses forbidden energy gap from valance band to conduction band.
- When this process is repeated, more and more electrons are available in conduction band, eventually leading to breakdown.

3.8.2 Avalanche Breakdown:-

- When an electric field is applied to an atom, electrons will drift from cathode to anode.
- During this motion, electrons gains kinetic energy from electric field and losses it during collision.
- Collision occurs due to sudden increase in applied voltage(impulse voltage) within a short time (about 10^{-8} seconds)
- During collision, free electron collide with a neutral particle and gives rise to two new electron and +ve ion.(ie ionization takes place)

- This process repeats until avalanche exceeds a critical size.
- Mathematically it is expressed as

$$e^{-} + A \rightarrow e^{-} + A^{+} + e^{-} \quad [\text{if } \varepsilon > v_i]$$

Here e^{-} = electron

A = atom

A^{+} = +ve ion

3.9 Thermal breakdown:-

Refer 2.4

3.10 Electrochemical Breakdown:-

- Electrochemical breakdown have a close relationship with thermal breakdown.
- When temperature rises, mobility of ions increases and hence electro chemical reaction takes place.
- The electro chemical reaction gradually decreases the insulation resistance and finally creates the dielectric breakdown.

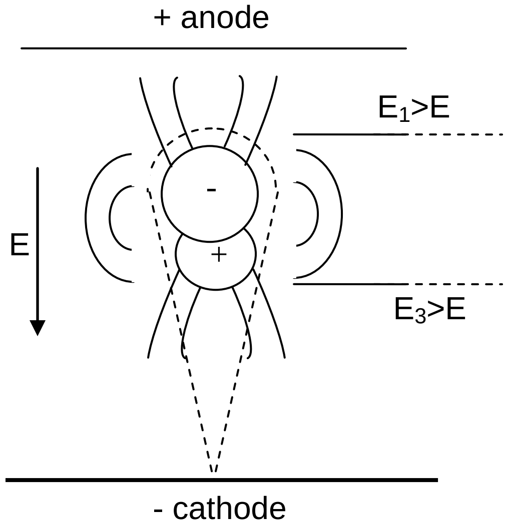
3.11 Discharge Breakdown:-

- Gas bubbles contained in the liquid/ solid dielectric requires small ionization potential than main dielectric.
- In the dielectric, gas bubbles ionize first and bombard of gaseous ions causing electric breakdown in it.

3.12 Defect Breakdown:-

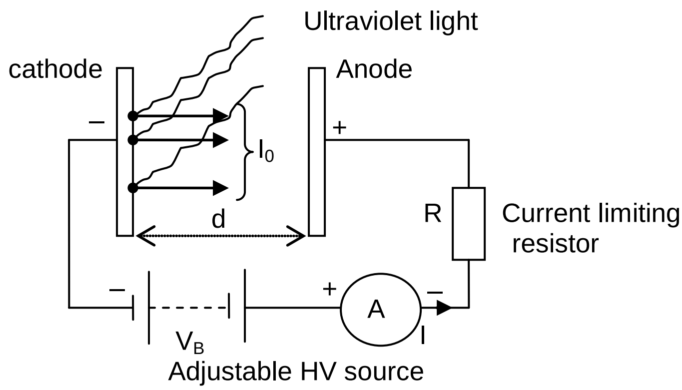
- The cracks and pores in the surface of dielectric collect moisture and other impurities, which leads to breakdown.

3.13 Streamer Mechanism of Breakdown:



- As per streamer mechanism, breakdown not only occurs due to ionization but also due to ionization process the gas pressure and the geometry of the gap.
- Streamer mechanism state that, a single electron starting at the cathode by ionization builds up an avalanche that crosses the gap. The electrons in the avalanche move very fast compared with the positive ions.
- By the time the electrons reach the anode the positive ions are in their original positions and form a positive space charge at the anode. This enhances the field, and the secondary avalanches are formed from a few electrons produced due to the photo-ionization in the space charge region.
- This occurs first near the anode where the space charge is maximum and a further increase in the space charge. This process is very fast and the positive space charge extends to the cathode very rapidly resulting in the formation of a streamer.

3.14 Townsends Criterion:-



- Townsends criterion explains generation of successive secondary avalanches to produce breakdown.
- Here additional electrons are produced at cathode by some external forces like UV light falling on it.
- This additional electrons themselves makes more ionization by participate in collision.
- In Townsend's type of discharge in gas, electrons get multiplied due to various ionization process and finally an electron avalanche is formed.

3.15 Suspended Particle Theory:-

- The presence of solid impurities like fibers or dispersed solid particles experiences force due to applied field.
- These solid particles contained in the liquids are aligned due to the force generated by applied electric field forms a stable chain bridge causing breakdown of liquid dielectric between the electrodes.
- This process is called suspended particle theory.

3.16 Testing of Transformer Oil:-

- The transformer oil is filled in the vessel of the testing device. Two standard-compliant test electrodes with a typical clearance of 2.5 mm are surrounded by the dielectric oil.
- A test voltage is applied to the electrodes and is continuously increased up to the breakdown voltage with a constant slew rate of e.g. 2 kV/s.
- At a certain voltage level breakdown occurs in an electric arc, leading to a

collapse of the test voltage.

- An instant after ignition of the arc, the test voltage is switched off automatically by the testing device. Ultra fast switch off is highly desirable, as the carbonization due to the electric are must be limited to keep the additional pollution as low as possible.

- The transformer oil testing device measures and reports the root mean square value of the breakdown voltage.

- After the transformer oil test is completed, the insultaion oil is stirred automatically and the test sequence is performed repeatedly. (Typically 5 Repetitions, depending on the standard)

- As a result the breakdown voltage is calculated as mean value of the individual measurements.

- Conclusion: The lower the resulting breakdown voltage, the poorer the quality of the transformer oil!

3.17 Breakdown of Vaccum Insulation:-

- Primary breakdown process in vaccum occurs due to field emission of electrons from cathode.
- When an electric field is applied to a vaccum metal surface, the surface potential energy barrier is thinned sufficiently so that free electrons entered in to vaccum, which leads to breakdown.
- Emission of additional electrons and positive ions with generation of photons from additional sources increase secondary emission process, which also lead to breakdown.
- If energy gained by electrons (acceleration due to collision) exceeds a critical value, localized heating would produce a vapour cloud , which is also suffient for breakdown.

3.18 Applications of Vaccum Insulators:-

- Particle accelerators
- X-ray and field emission tubes
- Electron microscopes
- Capacitors
- Circuit Breakers

3.19 Ageing of Insulators:-

CHAPTER – 4

SYLLABUS

Magnetic Materials – Origin of permanent magnetic dipole moment – classification of magnetic materials – curie-wiess law – Soft and Hard Magnetic Materials – Properties and applications of irons, alloys of irons- Ferrites – Magnetic materials used in electrical machines, instruments and relays

4.1 Origin of permanent magnetic dipole moment:-

- In 1913, Niels Bohr & Ernest Rutherford introduces Bohr theory.
- Bohr theory depicts that atom has a small +vely charged nucleus surrounded by electrons that travel in circular orbits.
- In all atoms, electrons revolving around the nucleus in different orbits. This revolving electron constitutes an electric current in these orbits. This current forms magnetic dipoles.
- Thus permanent magnetic dipoles are originated from spinning motion of electrons in an atom.

4.2 Classification of magnetic materials:-

Based on arrangement, magnetic materials are classified as

- Diamagnetic materials
- Paramagnetic materials
- Ferromagnetic materials
- Antiferro magnetic materials
- Ferrimagnetic materials

4.3 Diamagnetic materials:-

- Permanent magnetic dipoles are absent on diamagnetic materials
- If an external magnetic field is applied to a diamagnetic material it induces a magnetization M in opposite direction to the applied field intensity H.
- This means that relative permeability μ_r of diamagnetic materials are negative
- Magnetic susceptibility is independent of applied magnetic field strength.
- Eg:- Hydrogen, Bismuth

4.4 Paramagnetic Materials:-

- Permanent magnetic dipoles are present on paramagnetic materials.
- In the absence of external field, the dipoles are randomly oriented. Hence the net magnetization in any given direction is zero.

- When paramagnetic materials are placed in a magnetic field, it attracts the magnetic lines of force.
- Susceptibility is positive and depends greatly on temperature.
- Spin alignment is random.
- Magnetic susceptibility is independent of applied magnetic field strength.
- Eg:- Aluminium, Platinum

4.5 Ferromagnetic materials:-

- Due to large internal magnetic field, the permanent magnetic dipoles are aligned in the same direction with same magnitude and consequently large spontaneous magnetization results even in the absence of applied field.
- They exhibit magnetic hysteresis.
- During heating they lose their magnetization slowly.
- Susceptibility is positive and large.
- It consists of number of small regions which are spontaneously magnetized.
- Spin alignment is parallel in same direction
- Eg:- Iron, Nickel, Cobalt

4.6 Anti-ferro magnetic materials:-

- Spin alignment of neighboring atoms are anti-parallel.
- Susceptibility greatly depends on temperature.
- Susceptibility is positive and large.
- Initial susceptibility increases slightly with temperature and beyond Neel temperature the susceptibility decreases with temperature.
- Eg:- Ferrous oxide, Manganese oxide, Chromium oxide & salts of transition elements

4.7 Ferri-magnetic Materials:-

- In ferrimagnetic materials, unequal magnetic moments are aligned antiparallely.
- Susceptibility is positive and large.
- Actually ferri-magnetic materials are composed of different transition metals. Due to that large magnetization occurs.
- Eg:- Ferrous ferrite, Nickel ferrite

4.8 Curie –Wiess Law:-

- Curie –Wiess shown the variation of susceptibility (X) of ferromagnetic materials.
- Also it shows the temperature dependence of spontaneous magnetization.
-

$X = I/H = C / T- \theta$

This is called Curie-Wiess Law.

Here X = susceptibility

C = Curie constant

T = operating temperature

Θ = Curie temperature

- As per Curie-Wiess Law, the material is ferromagnetic below curie temperature and becomes paramagnetic above curie temperature.
- We must ensure the operating temperature is always below the curie temperature for maintain magnetic properties of materials.
- Thermal energy increases with increase in temperature which randomizes more and more of the parallel spins and at curie temperature, the parallel alignment of all spins vanishes resulting in the zero value of spontaneous magnetization. After that the substance becomes paramagnetic.
- A critical temperature at which the alignment of magnetic moments vanishes is called curie temperature.

4.9 Soft and Hard Magnetic Materials:-

Description	Soft magnetic materials	Hard magnetic materials
Area of hysteresis loop	smaller	larger
Hysteresis loss	Less	more
Permeability	larger	smaller
Magnetic reluctance	low	high
Susceptibility	low	high
Retentivity	smaller	larger
Coersivity	smaller	larger
Magneto-static energy	smaller	larger
Magnetization	easier	difficult
Demagnetization	easier	difficult
Eddi current loss	Less	more
Mechanical hardness	Less	more
Need of magnetic force for	Less	more

saturation		
Effect of change of magnetic field	large	less
Domain wall movement	considerable	negligible

Hard magnetic material

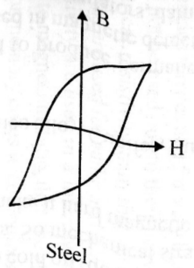


Figure 7.12 (a)

1. The above figure shows the nature of hysteresis loop of hard magnetic material.
2. Hard magnetic materials are magnetic materials which can not be easily magnetised and demagnetised.
3. They have large hysteresis loss due to large hysteresis loop area.
4. These materials have small values for permeability and susceptibility.

Soft magnetic material

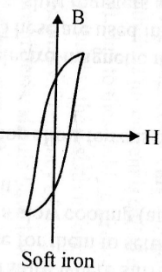


Figure 7.12 (b)

The above figure shows the nature hysteresis loop of soft magnetic material.

Soft magnetic materials are magnetic materials which can be easily magnetised and demagnetised.

They have small hysteresis loss due to small hysteresis loop area.

These materials have large values for permeability and susceptibility.

5.	The eddy current loss is more due to its smaller resistivity.	The eddy current loss is more due to its higher resistivity.
6.	In a hard magnetic material the domain wall movement is difficult owing to crystal imperfections and is irreversible in nature.	To obtain soft magnetic material the domain walls must be able to move easily and reversebly so that magnetisation changes by large amounts for small changes in the magnetising field.
7.	The coercivity and retentivity are large.	The coercivity and retentivity are small.
8.	In these materials, the irregularities (in the crystal structure) like mechanical strains will be more. Its magnetostatic energy is large.	These materials are free from irregularities (in the crystal structure) like strains or impurities. Its magnetostatic energy is very small.
9.	These are produced by heating the material and then plunging it suddenly into cold oil (quenching process) which sets up internal stresses. So mechanical strains are purposely introduced to make it hard magnetic material.	These are manufactured as follows : Heating the pure material to a temperature where sufficient movement of the atoms is possible for them to settle into an ordered lattice, followed by a slow cooling (annealing process) so as not to disturb it.
10.	Examples : Alnico alloy, Cunifes, Cunico and Silmanal.	Examples : Iron silicon alloy, ferrous nickel alloy, ferrite and garnets.
11.	These are used to produce permanent magnets. Permanent magnets are used in magnetic detectors, microphones, flux meters, voltage regulators, damping devices and magnetic separators.	These are used in electro-magnetic machinery and in transformer cores. These are used in switching circuits, microwave isolators, shift registers amd matrix storage of computers and to produce electromagnets.

4.10 Properties and applications of irons, alloys of irons:-

4.10 a) Properties & Applications of Soft magnetic materials:

Table 7.1 Important soft magnetic materials and their properties

Name of the alloy	Composition	Initial relative permeability (μ_r)	Resistivity ohm m	Hysteresis loss ($J\ m^{-3}$)	Other properties	Applications
1. Fe - Si alloy	96% Fe, 4% Si	500	0.6×10^{-6}	100	1. Max. relative permeability is 7000 2. Resistivity is six times that of pure iron.	Cores of power transformers
2. Permalloy	55% Fe, 45% Ni	2700	0.55×10^{-6}	120	1. Max. relative permeability is 25000 2. higher hardness	Cores of audio and video transformers and communication equipment.
3. Supermalloy	79% Ni, 16% Fe, 5% Mo	100,000	0.65×10^{-6}	20	1. Max. relative permeability is 8000,000 2. Very high hardness	Cores of audio and radio transformers where low coercivity is required.
4. Mu metal	77% Ni, 5% Cu, 2% Cr, 16% Fe	80,000	0.6×10^{-6}	16	1. Max. relative permeability is 100,000 2. high stable magnetic properties even at very high frequencies. 3. high corrosion resistance	Cores of audio and radio transformers.
5. Ni-Zn ferrite	(80% NiO + 20% ZnO) Fe_2O_3	500	10^6	35	1. very high resistivity 2. narrow hysteresis loop 3. max. relative permeability is 5000	Cores of audio and TV transformers
6. M_n-Z_n ferrite	(80% MnO + 20% ZnO) Fe_2O_3	2000	10^8	40	1. max. relative permeability is 2500 2. very high dielectric constant.	Microwave isolators and gyrators
7. Mg - Mn ferrite	(50% MgO + 50% MnO) Fe_2O_3	4000	10^8	20	1. rectangular hysteresis 2. very high resistivity and low eddy current losses.	Memory cores in computers
8. YIG	$Y_3Fe_5O_{12}$	3000	10^{11}	15	1. low eddy current losses	Microwave equipment

4.10 b) Properties & Applications of Hard magnetic materials:

Name of the alloy	Composition	Retentivity B_r weber m^{-2}	Coercivity H_c kA m^{-1}	Energy product $B_r H_c$ k J m^{-3}	Other properties	Applications
1. Martensitic high carbon steel	upto 1% C	0.9	3.98	3.58	1. high strength and high hardness	for making permanent magnets
2. Tungsten steel	6%W, 0.7%C 0.3% Mn, 93% Fe	1.05	5.57	5.85	1. higher strength and higher hardness than carbon steels	for making permanent magnets
3. High chrome steel	3.5%Cr, 1%C, 0.4%Mn 95.1%Fe	0.95	5.17	4.91	1. higher hardness 2. higher corrosion resistance	for making permanent magnets with stable energy product.
4. Cobalt steel (K S magnet steel)	36%Co, 7%W 3.5%Cr, 0.9%C 56.3Fe	0.95	18.31	17.4	1. high coercivity 2. high magnetic strength	for making permanent magnets.
5. Al-Ni-Co alloys	12%Co, 17% Ni, 10%Al, 6%Cu 55% Fe	0.8-1.2	60-120	48-144	1. high magnetic strength 2. high mechanical strength 3. produced by powder metallurgy 4. Alnico V is more powerful than Alnico II due to higher percentage of cobalt.	for making powerful permanent small magnets.
6. Cunifes	6%Cu, 36%Ni, 58% Fe	0.53	36	19	1. carbon free machinable alloy 2. magnetic properties are improved by hardening	for making large permanent magnets
7. Cunico	6%Cu, 40%Ni, 54% Co	1	40	40	1. Carbon free machinable alloy	for making large permanent magnets
8. Barium ferrite	$BaO.6Fe_2O_3$	0.2	140	29.4	1. high coercivity 2. high stable magnetic properties	for making powerful magnets.

NETIC MATERIALS 7.35

4.11 Ferrites:-

- Ferrites are compounds of two metallic oxide in which one is always iron oxide.
- Symbolically ferrites may be designated as (MetO. Fe_2O_3)
- Here "Met" stands for metals like Ni, Mn, Zn, Cu, Fe etc.
- In ferrites, unequal magnetic moments are aligned antiparallelly.
- Ferrites with narrow hysteresis loop forms soft magnetic materials which are used for making audio and television transformers, gyrators, induction cores etc.
- Ferrites with large hysteresis loop forms hard magnetic materials which are used for making permanent magnets for eg:- Barrium ferrite ($BaO6Fe_2O_3$)
- Properties:
    - High resistivity
    - Low power loss at high frequency
    - Poor mechanical strength

University Questions:

1. Bring out difference b/w soft and hard magnetic materials?
2. Distinguish between soft and hard magnetic materials?
3. Define ferromagnetic curie temperature

4. Draw a typical hysteresis loop for a ferromagnetic material? Show which part is reversible?
5. Explain ferromagnetic materials?
6. Explain the properties of any two magnetic materials?
7. Explain the properties of paramagnetic materials?
8. Distinguish between ferromagnetic & anti-ferromagnetic materials?
9. What are ferrites?
10. Briefly explain the properties & applications of iron and its important alloys in electrical applications?
11. Define Susceptibility?

    It measures the amount of magnetization (I) produced during the application of magnetic field(H). ie $X = I / H$

12. Define residual magnetism or remenance?

    It is the property of magnetic materials by which it retains some magnetization when the magnetic field is reduced to zero.

13. Define coercivity?

    It is the property of magnetic materials by which it requires a demagnetizing force to destroy residual magnetism in it.

CHAPTER – 5

SYLLABUS

Superconductor- Basic concept – Types – Characteristics – Applications

Solar energy materials – photo thermal conversion – solar selective coating for enhanced thermal energy collection – Photo-voltaic conversion – Silicon, GaAs , CdS , organic solar cells

4.1 Superconductors:-

- A superconductor is a conductor with zero/ negligible resistance.
- Superconductors are those elements, compounds and alloys of metals and non-metals which exhibit extra ordinary magnetic and electric behavior at extremely low temperature.
- Normal conductors become superconductor above transition temperature Tc (It is a temperature atwhich electrical resistivity of metal falls to zero).
-

4.2 Types of Superconductors:-

Superconductors are broadly classified in to two

1) Type-I Superconductors
2) Type-II Superconductors

- Type-I superconductor consist of basic conductive elements that are used in electrical devices

Element	Tc
Sulpher	17°k
Aluminium	-4.15°k
Mercury	-1.17°k
Lead	-7.2°k
Zinc	0.85°k

- Type-II superconductors are made from alloys of metals.

Compound	Tc
CuS	1.6°k
Nb3Sn	18.3°k
Pb2Au	7°k
Alloys	**Tc**
ceramic	34°k

4.3 Properties / Characteristics of superconductors:-

Magnetic flux density = 0

Relative permeability = 0

Specific resistance = 0

Magnetic susceptibility = -1

Power loss = 0

4.4 Applications of superconductors:-

- Low loss power cables
- RF & microwave filters
- Magnetic Resonance Imaging
- Nuclear magnetic resonance
- Maglev trains
- Switching elements

4.5 Photo –Thermal Conversion:-

- Conversion of solar energy directly into heat energy is called photo thermal conversion.
- A solar collector is used to absorb solar radiation and converts it in to heat energy.
-

4.6 Solar Coatings:-

An efficient way to maximize the harnessing of solar energy is to apply coatings of some specific materials to absorber surface. Coatings are used for this purpose. Coatings are classified into two

i) Non-selective solar coatings

ii) Selective solar coatings

4.7 Non-selective solar coatings:-

- Non-selective solar coatings increases absorptivity and emissivity
- In solar thermal applications, a coating should have high absorptivity, but a low emissivity. So that it retains the trapped thermsl energy.
- This limits the applicability of non-selective coatings for solar thermal conversion technology.
- Example: Black paint

4.8 Solar Selective Coating for Enhanced Thermal Energy Collection:-

- The solar selective coatings allows incoming solar radiations to pass through it and blocks the emittance of longer wavelength thermal radiations to achieve high temperature.
- Reflection and transmittance properties of optical components are selectively modified/ enhanced by using solar selective coatings,.
- Solar selective coatings are mainly classified into three
  - i) Cold mirror coatings
  - ii) Heat mirror coatings
  - iii) Anti-reflection coatings

4.9 Cold mirror coatings:-

- Cold mirror coatings are designed to reflect visible light and to transmit infrared radiation/heat.
- So cold mirrors are work as heat transmitting filters and at the same time they offer very high visible light reflection.
- Properties:
  - Very high optical reflection
  - Excellent reflection uniformity
  - High operating temperature (upto 400°C)
  - Good mechanical stability
  - Designed for incidence angle upto 45°
- Applications:
  - Scanners and barcode reader optics
  - IR filters
  - Laser beam separation

4.10 Heat mirror coatings:-

- Heat mirror coatings are designed to reflect infrared radiation/heat and to transmit visible light.
- So hot mirror is used to remove undesired infrared energy from light energy.
- Such mirrors reflects IR wavelength while they are transparent in visible spectrum.
- Properties:
  - Very good infraredf reflection upto 1100nm
  - High and neutral optical transmittivity

- High operating temperature (upto 400°C)
- Transmits cold light
- 100% dielectric multy layer construction

➢ Applications:

- Optical IR mirrors
- Mirror for eye tracking system
- IR photography filters
- Lens system protection
- IR imaging filters

4.11 Anti-reflection coatings:-

➢ Anti-reflection coatings are used to reduce reflection losses by increasing efficiency of transmittance of visible light with the help of multi layer construction with different refractive indices.

➢ Anti-reflection coatings consist of alternative thin film coated layers each with different refractive indices. This helps to collect light energy of different wavelengths.

➢ Properties:

- Very low residual reflection.
- High transmittance of visible light
- Low light absorptivity.
- Broadband multilayer coatings

➢ Applications:

- Laser scanner optics
- Holography applications
- Camera lens optics
- Laser glass window
-

4.12 Solar Cell/ Photo voltaic conversion:-

➢ A solar cell is a solid state electrical device which converts energy of light directly in to electrical energy by the photo voltaic effect.

➢ Following are the different types of solar cell.

i) Mono-crystalline Silicon solar cell

ii) Poly-crystalline Silicon solar cell

iii) Thin film solar cell

- **Mono-crystalline Silicon solar cell:-**
  - Mono-crystalline solar cells are made out of silicon ingots, which are cylindrical in shape.
  - Advantages:
    - Highest efficiency(15-20%).
    - Space-efficient. They require the least amount of space compared to any other types.
    - Monocrystalline solar panels live the longest. Most solar panel manufacturers put a 25-year warranty on their monocrystalline solar panels.
    - Tend to perform better than similarly rated polycrystalline solar panels at low-light conditions.
  - Disadvantages
    - Monocrystalline solar panels are the most expensive
    - If the solar panel is partially covered with shade, dirt or snow, the entire circuit can break down.

4.14 Poly-crystalline Silicon solar cell:

- It consist of various crystalline sizes of silicon
- Raw silicon is used to make poly-crystalline silicon solar cell.
- Advantages:
  - Low amount of waste
  - Reduced cost
  - Respond to heat change is low
- Disadvantages
  - Low efficiency (13-16%)
  - Lower space efficiency(required more space)
  - Non- uniform look

4.15Thin solar cell:

- Thin film solar cells are manufactured by depositing one or more thin layers of photo-voltaic material onto a substrate like glass plate, plastic, stainless steel etc.

- Advantages:

  - Mass production is simple
  - Good looking
  - Flexible making
  - Low heat tolerance

- Disadvantages

  - Low efficiency (7-13%)
  - Requires large space
  - High Degradation rate.

- Thin film solar cells are classified as
  - i) Amorphous silicon solar cell
  - ii) Gallium Arsenide solar cell
  - iii) Cadmium Sulphide solar cell
  - iv) Organic solar cell

4.16 Amorphous silicon solar cell:-

- Amorphous silicon is made by depositing thin layers of silicon on substrate like glass.
- Least amount of silicon (about 1%) is required to make amorphous silicon solar cell

- Advantages:

  - Flexible in making
  - Light weight
  - Working under poor light condition

- Disadvantages

  - Low efficiency (7-13%)
  - .degrade fastly

CHAPTER – 6

SYLLABUS

Optical microscopy- Electron microscopy- Photoelectron spectroscopy- Atomic absorption spectroscopy- Introduction to Biomaterials & nanomaterials

6.1Microscopy:-

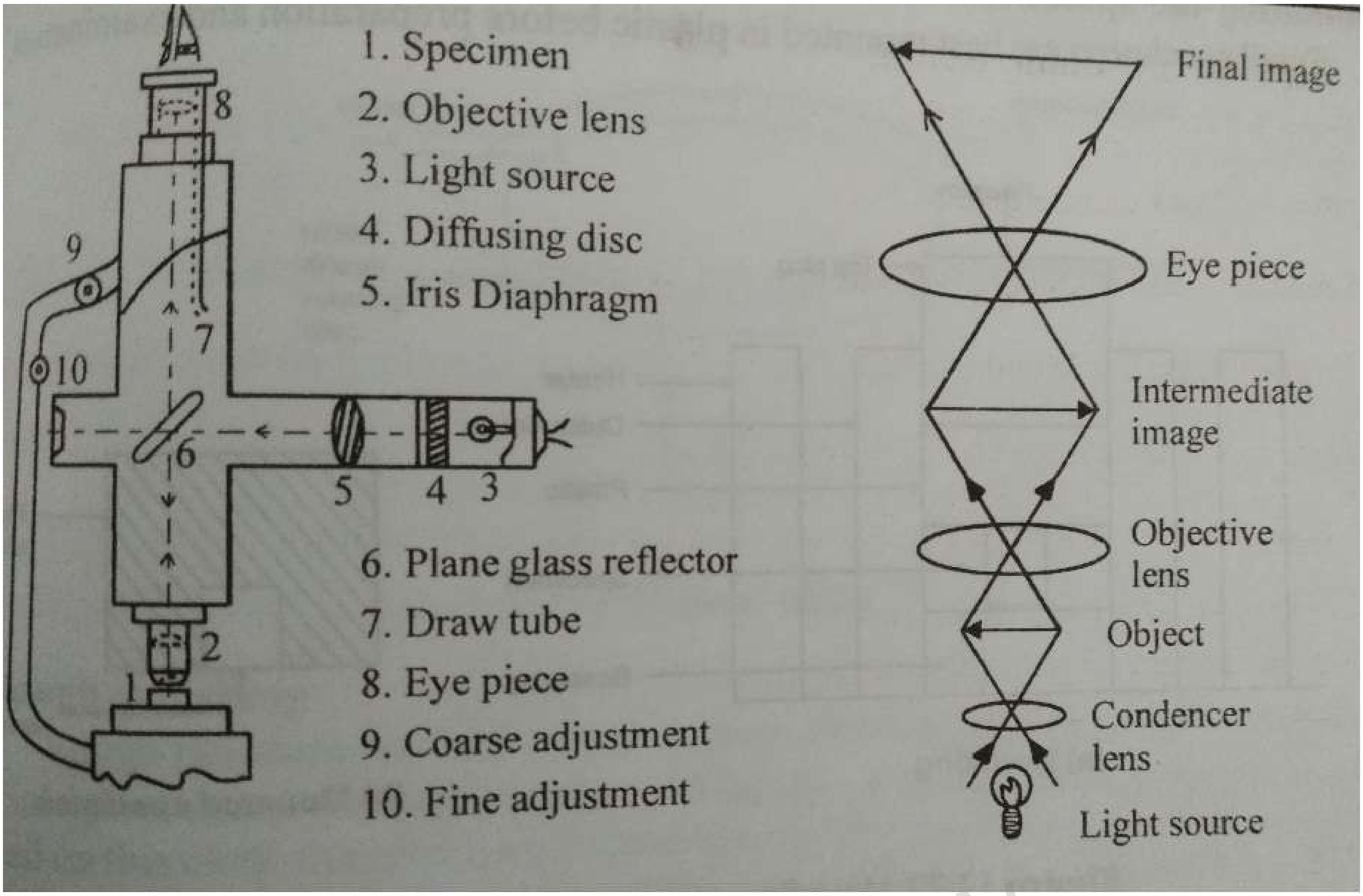
It is the technical field of using microscopes to view objects and areas of objects that cannot be seen with the naked eye (objects that are not within the resolution range of the normal eye). There are three well-known branches of microscopy: optical, electron, and scanning probe microscopy.

Optical or light microscopy involves passing visible light transmitted through or reflected from the sample through a single or multiple lenses to allow a magnified view of the sample.[1] The resulting image can be detected directly by the eye, imaged on a photographic plate or captured digitally. The single lens with its attachments, or the system of lenses and imaging equipment, along with the appropriate lighting equipment, sample stage and support, makes up the basic light microscope.

Optical & electron microscopy involve the diffraction, reflection, or refraction of electromagnetic radiation/electron beams interacting with the specimen, and the collection of the scattered radiation or another signal in order to create an image

6.2 Optical microscopy:-

It is a type of microscope which uses visible light and asystem of lenses to magnify images of small samples.



- Here source of light is kept inside the microscope tube itself and this light is diffused with the help of diffusing disc.
- The width of light beam is controlled by iris diaphra.
- The incident light strikes the plane glass reflector kept at 45° and is partially reflected down on the specimen.
- This rays of light get returned by reflection from specimen, pass through objective lens & glass reflector to form final image which can be seen through eye piece.
- A photographic camera may be mounted above eye piece inorder to record the metallographic structure of specimen.

6.3 Electron microscopy:-

It is a type of microscope that uses a beam of electrons to create an image of specimen. It is used for obtaining high resolution images of living and non-living specimen, which is helpful in studying of detailed structure of tissues, cells etc.

There are two basic models of the electron microscopes: *Scanning electron microscopes* (SEM) and *transmission electron microscopes* (TEM). In a SEM, the secondary electrons produced by the specimen are detected to generate an image that contains topological features of the specimen. The image in a TEM, on the other hand, is generated by the electrons that have transmitted through a thin specimen. Let us see how these two microscopes work and what kind of information they can provide:

6.4 Scanning electron microscope(SEM):-

Figure 5.2 shows a simplified schematic diagram of a SEM. The electrons produced by the electron gun are guided and focused by the magnetic lenses on the specimen.

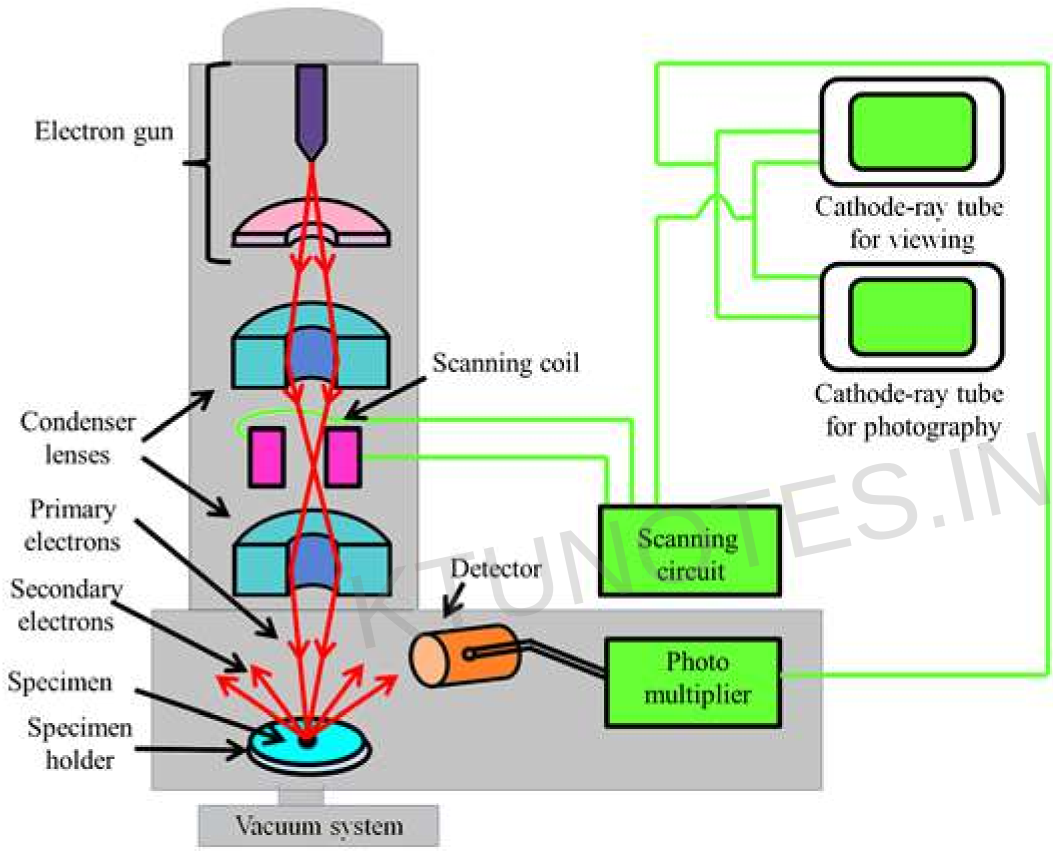


Figure6.2 A simplified schematic diagram of a scanning electron microscope.

The focused beam of electrons is then scanned across the surface in a raster fashion. This scanning is achieved by moving the electron beam across the specimen surface by using deflection/scanning coils. The number of secondary electrons produced by the specimen at each scanned point are plotted to give a two dimensional image.

In principle, any of the signals generated at the specimen surface can be detected. Most electron microscopes have the detectors for the secondary electrons and the backscattered electrons

A secondary electron detector is biased with positive potential to attract the low energy secondary electrons. Detector for backscattered electrons is not biased; the high energy backscattered electrons strike the unbiased detector. As backscattered electrons come from a significant depth within the sample, they do not provide much information about the specimen topology. However, backscattered electrons can provide useful information about the composition of the sample; materials with higher atomic number produce brighter images.

6.5 Transmission electron microscope(TEM):-

The first electron microscope was developed by Knoll and Ruska in 1930s. It was a transmission electron microscope; the electrons were focused on a thin specimen and the electrons transmitted through the specimen were detected. Figure 5.3 shows a simplified optical diagram comparing a light microscope with a transmission electron microscope.

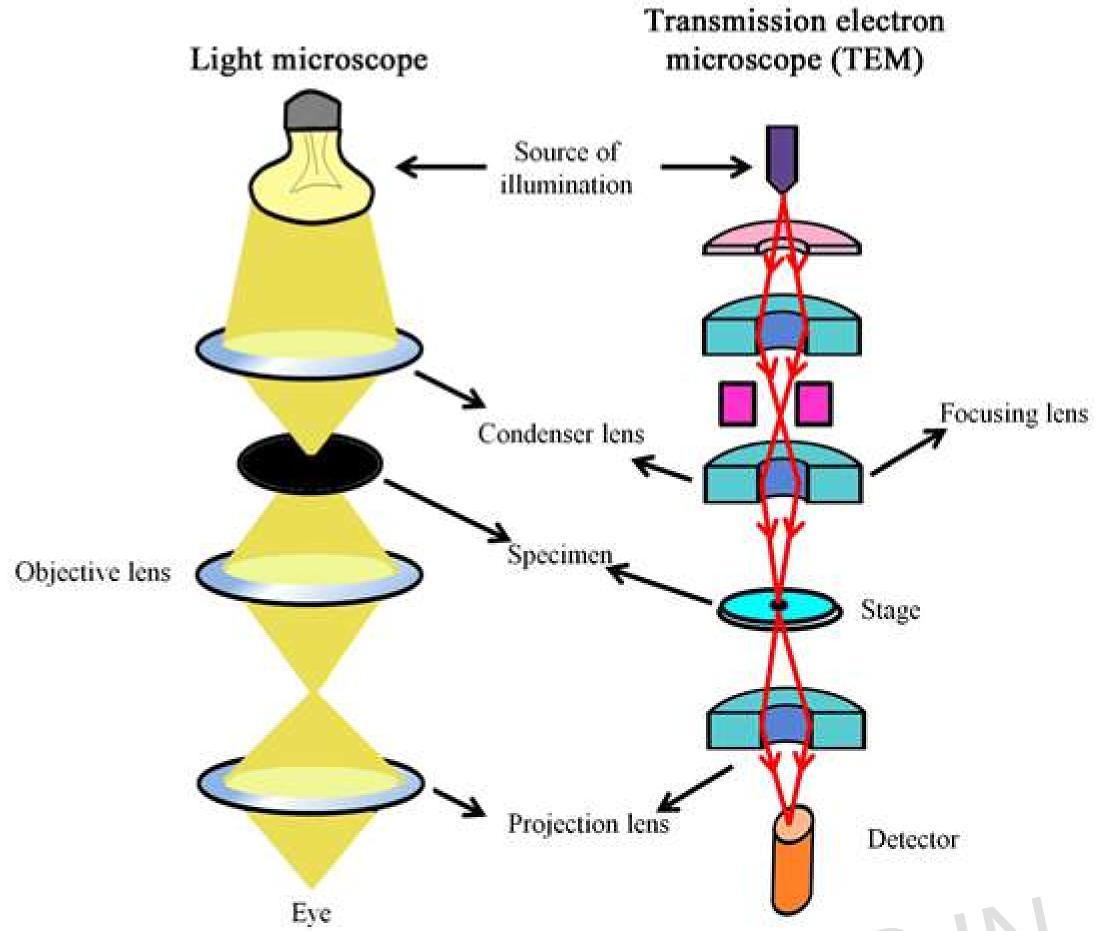
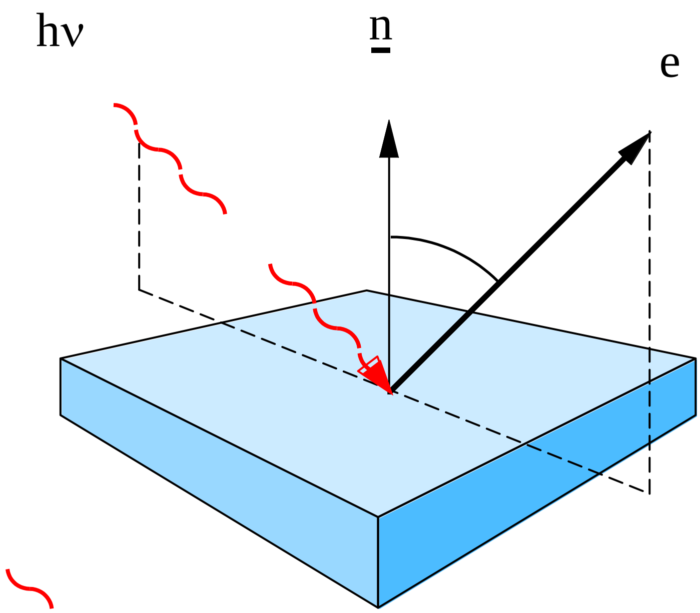


Figure 6.3 A simplified comparison of optics in a light microscope with that in a TEM.

Transmission electron microscopes usually have thermionic emission guns and electrons are accelerated anywhere between 40 – 200 kV potential. However, TEM with >1000 kV acceleration potentials have been developed for obtaining higher resolutions. Owing to their brightness and very fine electron beams, field emission guns are becoming more popular as the electron guns.

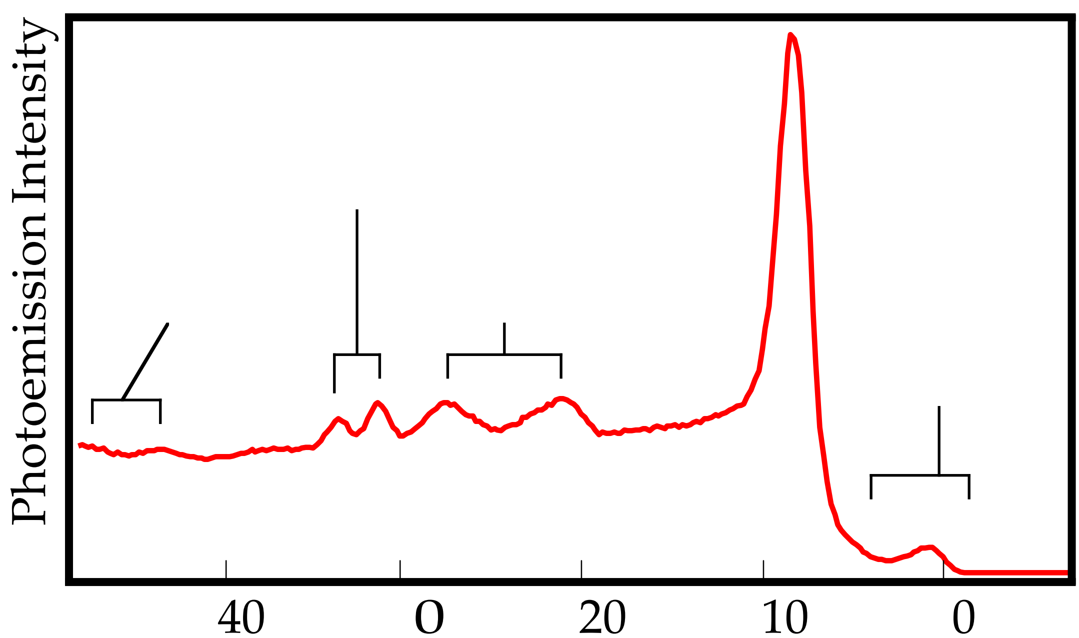
6.6 Photoelectron Spectroscopy:-

In the photoelectric effect, first explained by Einstein in 1905, a photon of light ejects an electron from the surface of a sample. When the photon is absorbed by an electron, the kinetic energy of the electron is increased by an amount equal to the photon energy (by the conservation of energy). Some electrons will travel deeper into the sample, but some may head towards the surface. Providing that an electron is energetic enough to overcome the work function (Φ) of the sample (typically a few electron-volts), then it will leave the surface and can be detected.



By absorbing a photon, an electron is kicked from a low energy state (○) inside an atom into a higher energy state (•) in which it is free to move through the sample.

Some of the photoelectrons energy is used to free the electron from its parent atom (the binding energy), and some is used to overcome the workfunction. Whatever is left is measured as the kinetic energy of the photoelectron. Thus if we measure the kinetic energy of an electron, and we know the photon energy (hv) and the workfunction (Φ) of the sample, then we can calculate the binding energy of the electron.

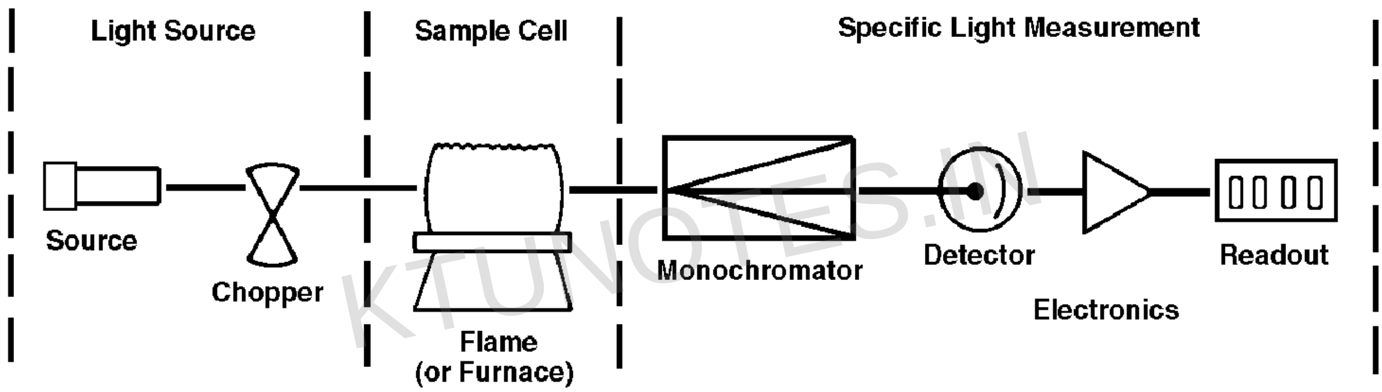


Binding Energy I eV

The photoelectron spectra are often displayed as graphs of numbers of photoelectrons emitted per second (the photocurrent) plotted against kinetic energy or binding energy (above). In this spectrum peaks are seen which correspond to electronic energy levels in atoms of tungsten and gadolinium. A binding energy scale has been used, so that zero corresponds to the most energetic electrons in the sample (the valence electrons in the outer electron shells of the atoms) and larger binding energies correspond to electrons more tightly bound to their parent atoms.

6.7 Atomic absorption spectroscopy:-

In atomic absorption, these functional areas are implemented by the components illustrated in Figure below. A light source which emits the sharp atomic lines of the element to be determined is required. The most widely used source is the hollow cathode lamp.



It is also required that the source radiation be modulated (switched on and off rapidly) to provide a means of selectively amplifying light emitted from the source lamp and ignoring emission from the sample cell. Source modulation can be accomplished with a rotating chopper located between the source and the sample cell, or by pulsing the power to the source.

Special considerations are also required for a sample cell for atomic absorption. An atomic vapor must be generated in the light beam from the source. This is generally accomplished by introducing the sample into a burner system or electrically heated furnace aligned in the optical path of the spectrophotometer.

Several components are required for specific light measurement. A monochromator is used to disperse the various wavelengths of light which are emitted from the source and to isolate the particular line of interest.

The wavelength of light which is isolated by the monochromator is directed onto the detector, which serves as the ‘‘eye’’ of the instrument. This is normally a photomultiplier tube, which produces an electrical current dependent on the light intensity. The electrical current from the photomultiplier is then amplified and processed by the instrument electronics to produce a signal which is a measure of the light attenuation occurring in the sample cell. This signal can be further processed to produce an instrument readout directly in concentration units.