

**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.

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

$$\text{I.e. } K = \frac{1}{\rho}$$

**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, Manganese, Platinum, Constantan etc)

**1.5 Properties of Low resistivity material:-**

- (i) Low resistance-temperature coefficient:-

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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 possess 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 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.

### 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 ( $28 \times 10^{-9}$ )

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

→ Due to high melting point (  $1083^{\circ}\text{C}$ ), suitable for use at high temperature.

→ High tensile strength (  $300\text{-}350\text{MPa}$ ) 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 ( $50\text{-}70\text{ MPa}$ ), 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 ( $3300^{\circ}\text{C}$ ).
- 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%) ]

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- 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 generator etc.

### **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?

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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 carries 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 welded
- 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

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### 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 semiconductors 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)

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- 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  $\alpha_e$  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



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$$\alpha_e = 4\pi\epsilon_0 R^3$$

### **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,

$$P_i = \alpha_i E$$

Where  $\alpha_i$  is the proportionality constant & is defines the ionic polarizability and is independent of temperature.

### **1.19 Dipolar or Orientation Polarization:-**

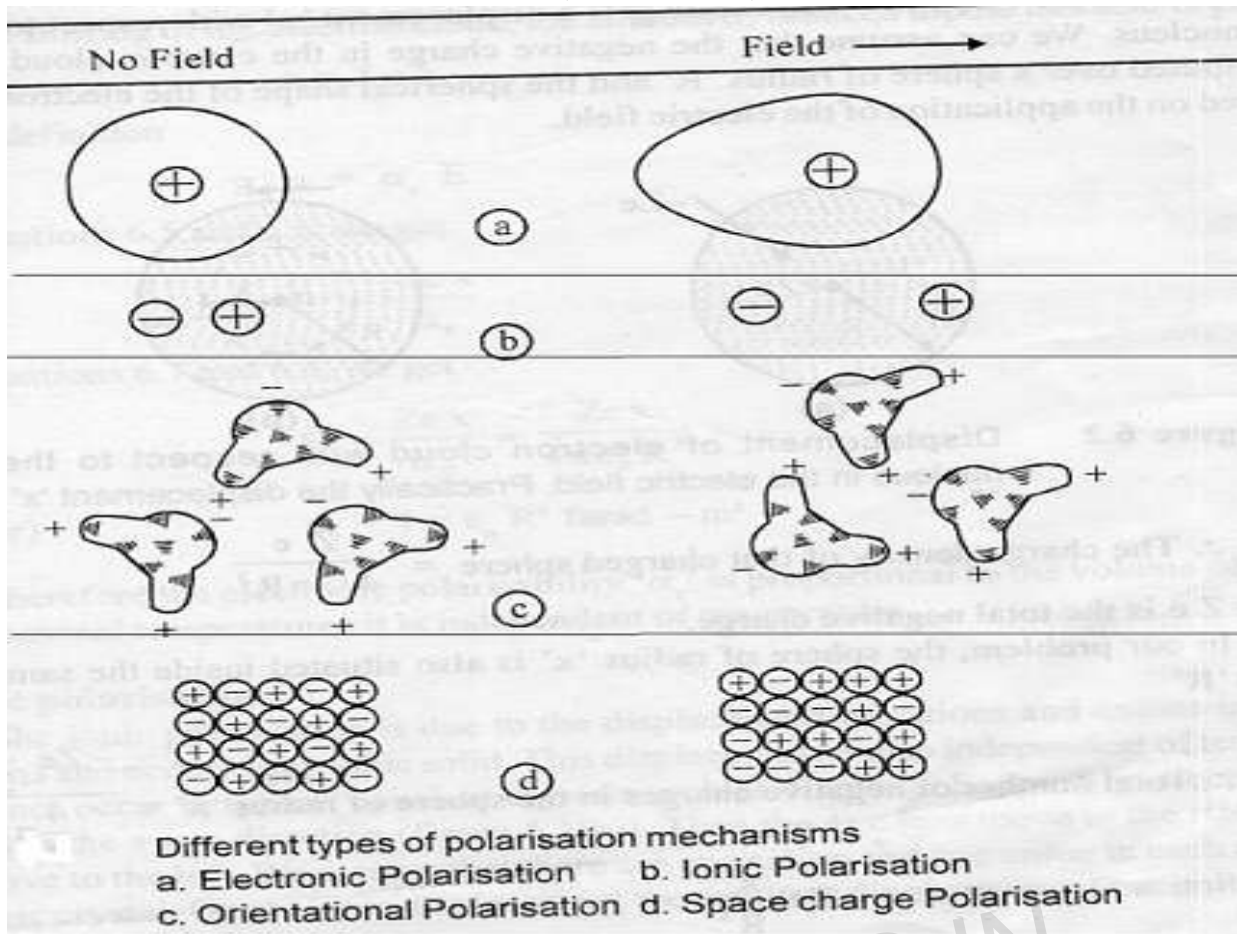
→ Polarization due to the rotation (orientation) of the molecule of a polar dielectric having constant dipole moment in the direction of an electric field is called dipolar polarization.

→ 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

$$P_o = \alpha_o E$$

Where  $\alpha_o = \frac{m^2}{3kBT}$

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



### 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

$$P = N \alpha_e E_i$$

$$P = N \alpha_e \left[ E + \frac{P}{3\epsilon_0} \right]$$

$$\text{Where } E_i = E + \frac{P}{3\epsilon_0} \text{ (Lorentz electric field)}$$

$$P = N \alpha_e E + \frac{N \alpha_e P}{3\epsilon_0}$$

$$P - \frac{N \alpha_e P}{3\epsilon_0} = N \alpha_e E$$

$$P \left( 1 - \frac{N \alpha_e}{3\epsilon_0} \right) = N \alpha_e E$$

$$P = \frac{N \alpha_e E}{1 - \frac{N \alpha_e}{3\epsilon_0}} \quad \dots\dots(1)$$

We know that

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$$D = P + \epsilon_0 E$$

$$P = D - \epsilon_0 E$$

$$\frac{P}{E} = \frac{D}{E} - \epsilon_0 = \epsilon_0 \epsilon_r - \epsilon_0 \quad (\text{Where } D = \epsilon_0 \epsilon_r E)$$

$$P = (\epsilon_0 \epsilon_r - \epsilon_0)E \quad \dots\dots(2)$$

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

$$(\epsilon_0 \epsilon_r - \epsilon_0)E = \frac{N \alpha_e E}{1 - \frac{N \alpha_e}{3\epsilon_0}}$$

$$1 - \frac{N \alpha_e}{3\epsilon_0} = \frac{N \alpha_e E}{(\epsilon_0 \epsilon_r - \epsilon_0)E}$$

$$1 = \frac{N \alpha_e}{3\epsilon_0} + \frac{N \alpha_e}{(\epsilon_0 \epsilon_r - \epsilon_0)}$$

$$1 = \frac{N \alpha_e}{3\epsilon_0} + \frac{3 N \alpha_e}{3\epsilon_0(\epsilon_r - 1)}$$

$$1 = \frac{N \alpha_e}{3\epsilon_0} \left[ 1 + \frac{3}{(\epsilon_r - 1)} \right]$$

$$1 = \frac{N \alpha_e}{3\epsilon_0} \left[ \frac{\epsilon_r - 1 + 3}{\epsilon_r - 1} \right]$$

$$1 = \frac{N \alpha_e}{3\epsilon_0} \left[ \frac{\epsilon_r + 2}{\epsilon_r - 1} \right]$$

$$\frac{N \alpha_e}{3\epsilon_0} = \frac{1}{\frac{\epsilon_r + 2}{\epsilon_r - 1}}$$

$$\boxed{\frac{N \alpha_e}{3\epsilon_0} = \frac{(\epsilon_r - 1)}{(\epsilon_r + 2)}}$$

Where  $N$  = number of molecules per unit volume

$\epsilon_0$  = absolute permittivity

$\epsilon_r$  = relative permittivity

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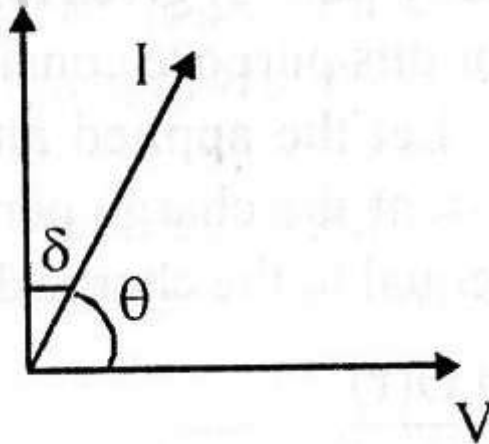
The above equation is known as clausius- Mosotti relation. This equation is very helpful to find electronic polarisability knowing the value of  $\epsilon_r$  of the medium.

### 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

$$m = q \cdot d$$

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### 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.

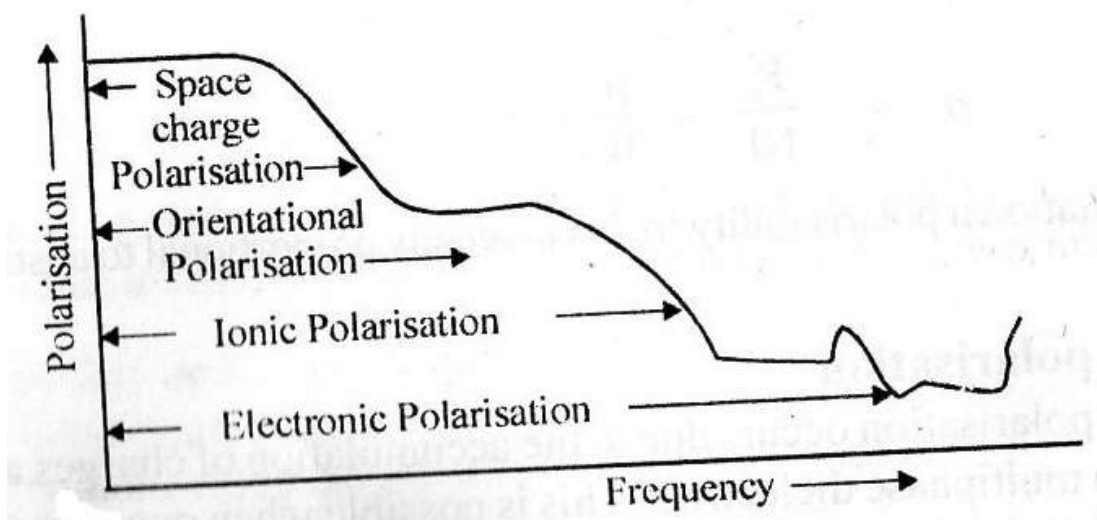
### 16. What is mean by Lorentz local field in a dielectric?

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

$$E_i = E + \frac{P}{3\epsilon_0} \text{ (Lorentz electric field)}$$

### 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?

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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

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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

**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.

**3.4 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.

### 3.5 Purely electrical breakdown:-

It occurs due to intrinsic breakdown.

### 3.6 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.

### 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.

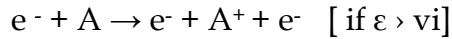
#### 3.8.2 Avalanche Breakdown:-

- 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)



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



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.

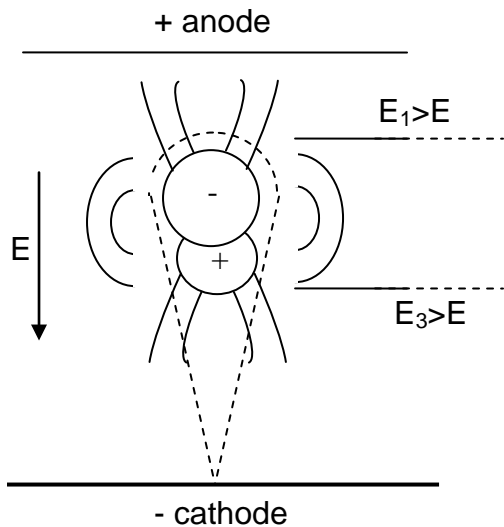
### 3.11 Discharge Breakdown:-

- 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.

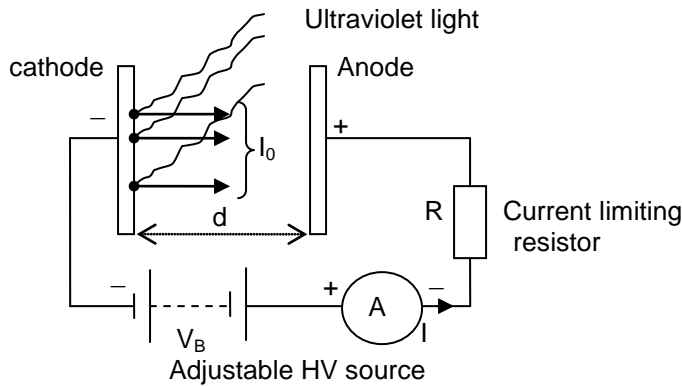
### 3.12 Defect Breakdown:-

- 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 arc 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 insulating 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 Vacuum Insulation:-

- Primary breakdown process in vacuum occurs due to field emission of electrons from cathode.
- When an electric field is applied to a vacuum metal surface, the surface potential energy barrier is thinned sufficiently so that free electrons enter into vacuum, which leads to breakdown.
- Emission of additional electrons and positive ions with generation of photons from additional sources increase secondary emission process, which also leads 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 sufficient for breakdown.

**3.18 Applications of Vacuum Insulators:-**

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

**3.19 Ageing of Insulators:-**

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**SYLLABUS**

Magnetic Materials – Origin of permanent magnetic dipole moment – classification of magnetic materials – Curie-Weiss 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
- Antiferromagnetic 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  $\mu_r$  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.

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- 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.
-

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

This is called Curie-Wiess Law.

Here  $X$  = susceptibility

$C$  = Curie constant

$T$  = operating temperature

$\theta$  = 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.

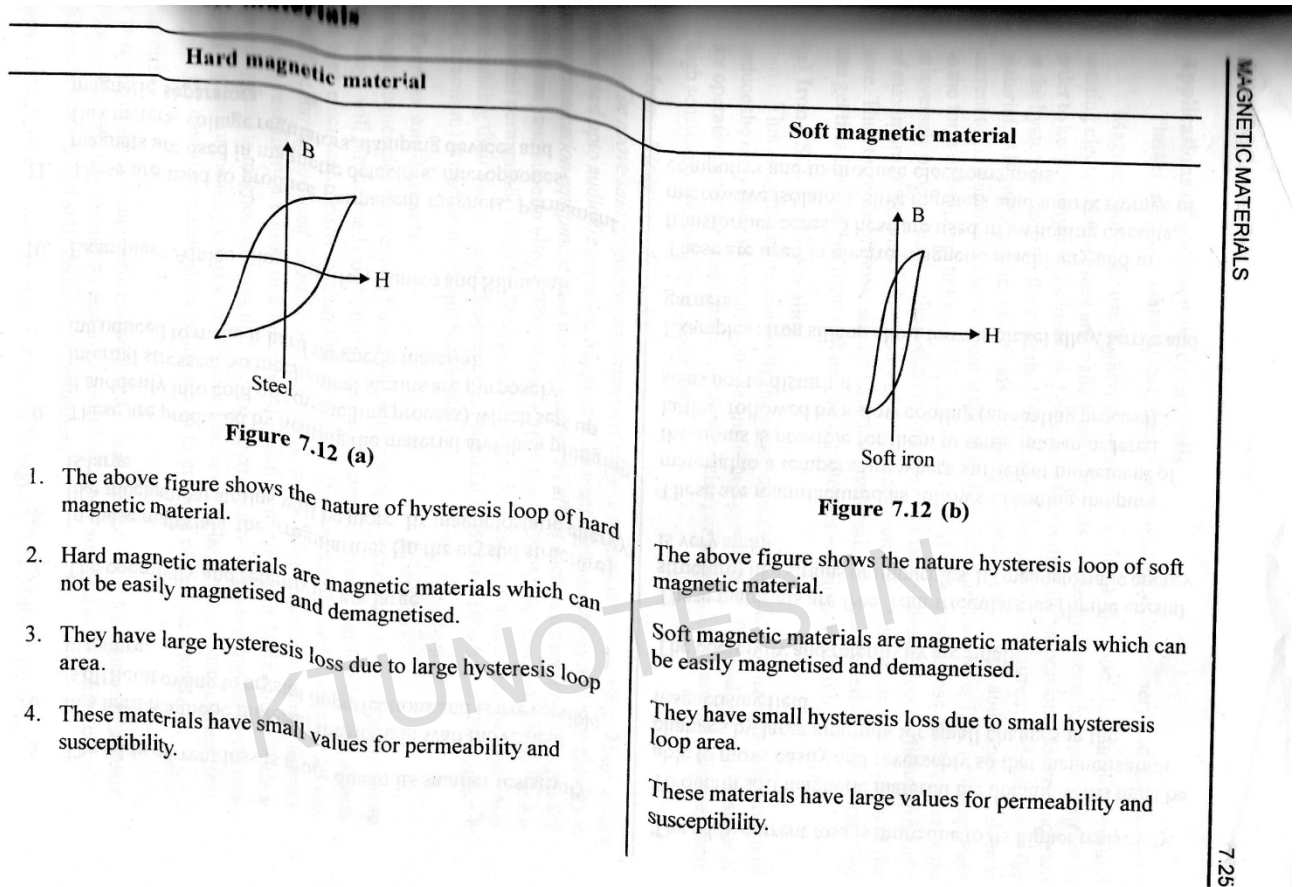
### 4.9 Soft and Hard Magnetic Materials:-

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



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



5. The eddy current loss is more due to its smaller resistivity.
6. In a hard magnetic material the domain wall movement is difficult owing to crystal imperfections and is irreversible in nature.
7. The coercivity and retentivity are large.
8. In these materials, the irregularities (in the crystal structure) like mechanical strains will be more. Its magnetostatic energy is large.
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.
10. Examples : Alnico alloy, Cunifes, Cunico and Silmanal.
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.

The eddy current loss is more due to its higher resistivity.

To obtain soft magnetic material the domain walls must be able to move easily and reversibly so that magnetisation changes by large amounts for small changes in the magnetising field.

The coercivity and retentivity are small.

These materials are free from irregularities (in the crystal structure) like strains or impurities. Its magnetostatic energy is very small.

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.

Examples : Iron silicon alloy, ferrous nickel alloy, ferrite and garnets.

These are used in electro-magnetic machinery and in transformer cores. These are used in switching circuits, microwave isolators, shift registers and matrix storage of computers and to produce electromagnets.

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### 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 ( $\mu_r$ )	Resistivity ohm m	Hysteresis loss ( $J m^{-3}$ )	Other properties	Applications
1. Fe - Si alloy	96% Fe, 4% Si	500	$0.6 \times 10^{-6}$	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	$0.55 \times 10^{-6}$	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	$0.65 \times 10^{-6}$	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	$0.6 \times 10^{-6}$	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 <sub>n</sub> 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



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### 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	1.05	5.57	5.85	1. higher strength and higher hardness than carbon steels	for making permanent magnets
3. High chrome steel	0.3% Mn, 93% Fe 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 56.3% Fe	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	$BaO \cdot 6Fe_2O_3$	0.2	140	29.4	1. high coercivity 2. high stable magnetic properties	for making powerful magnets.

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### 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 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 ( $BaO6Fe_2O_3$ )
- 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

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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.

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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

**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  $T_c$  ( It is a temperature at which 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	$T_c$
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	$T_c$
CuS	1.6°k
Nb <sub>3</sub> Sn	18.3°k
Pb <sub>2</sub> Au	7°k
Alloys	$T_c$
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 thermal 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 infrared reflection upto 1100nm
  - High and neutral optical transmittivity



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- 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.

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### ➤ 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

## **SYLLABUS**

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

### **6.1 Microscopy:-**

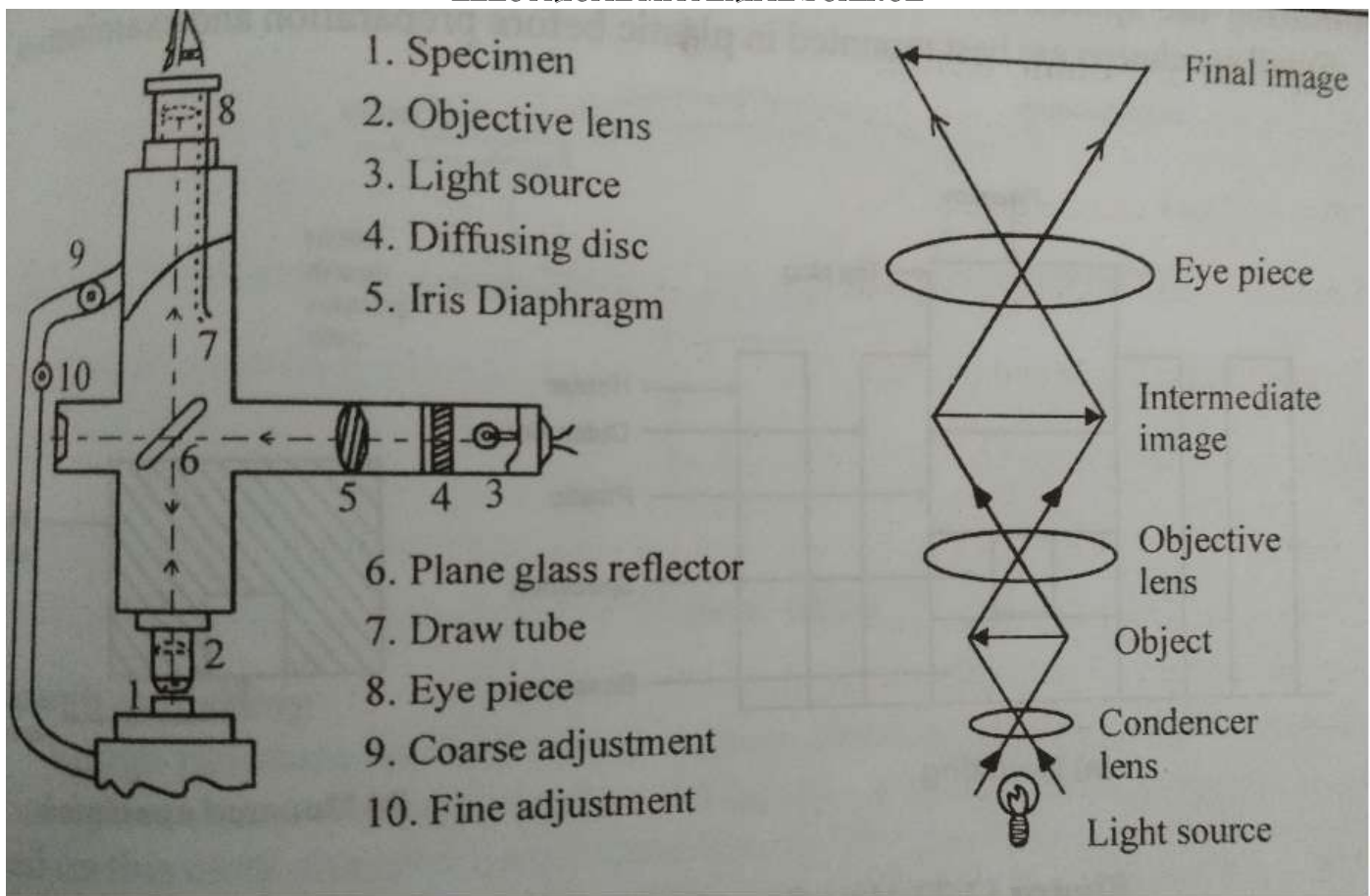
It is the technical field of using microscopes to view objects and areas of objects that cannot be seen with the naked eye (objects that are not within the resolution range of the normal eye). There are three well-known branches of microscopy: optical, electron, and scanning probe microscopy.

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.<sup>[1]</sup> 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 a system 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 diaphragm.
- The incident light strikes the plane glass reflector kept at  $45^\circ$  and is partially reflected down on the specimen.
- These 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 in order to record the metallographic structure of specimen.

### 6.3 Electron microscopy:-

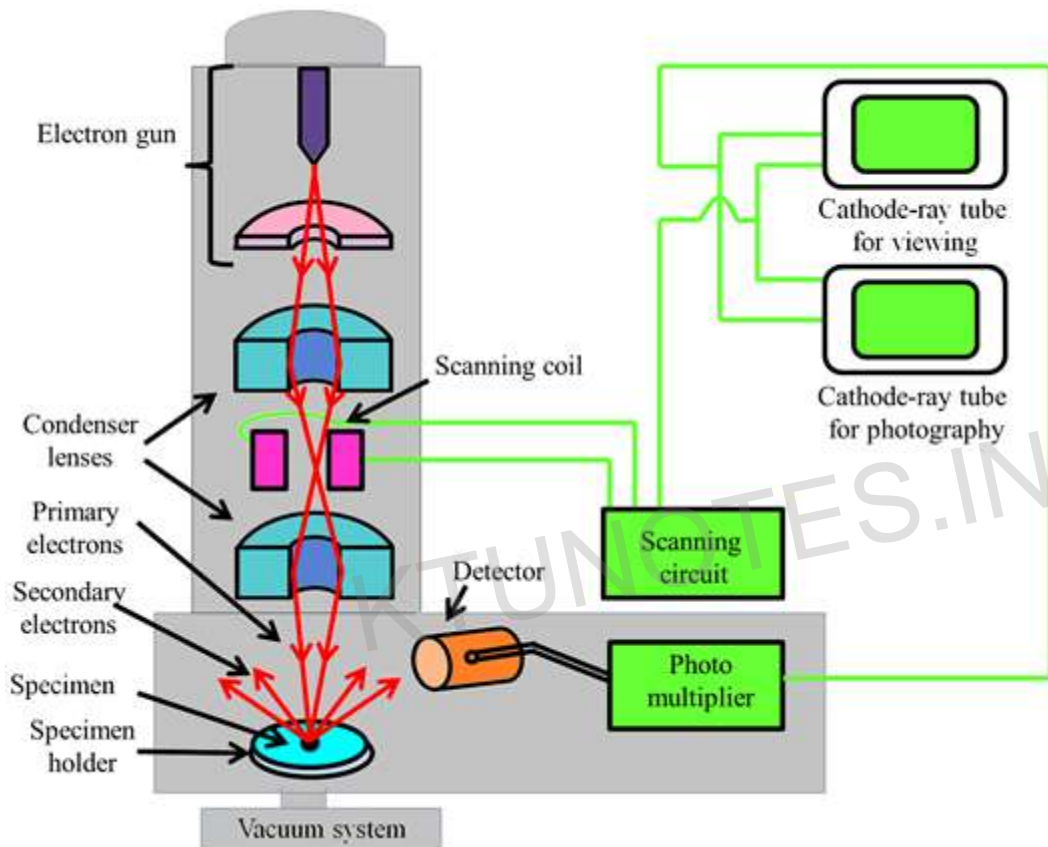
It is a type of microscope that uses a beam of electrons to create an image of specimen. It is used for obtaining high resolution images of living and non-living specimen, which is helpful in studying of detailed structure of tissues, cells etc.

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

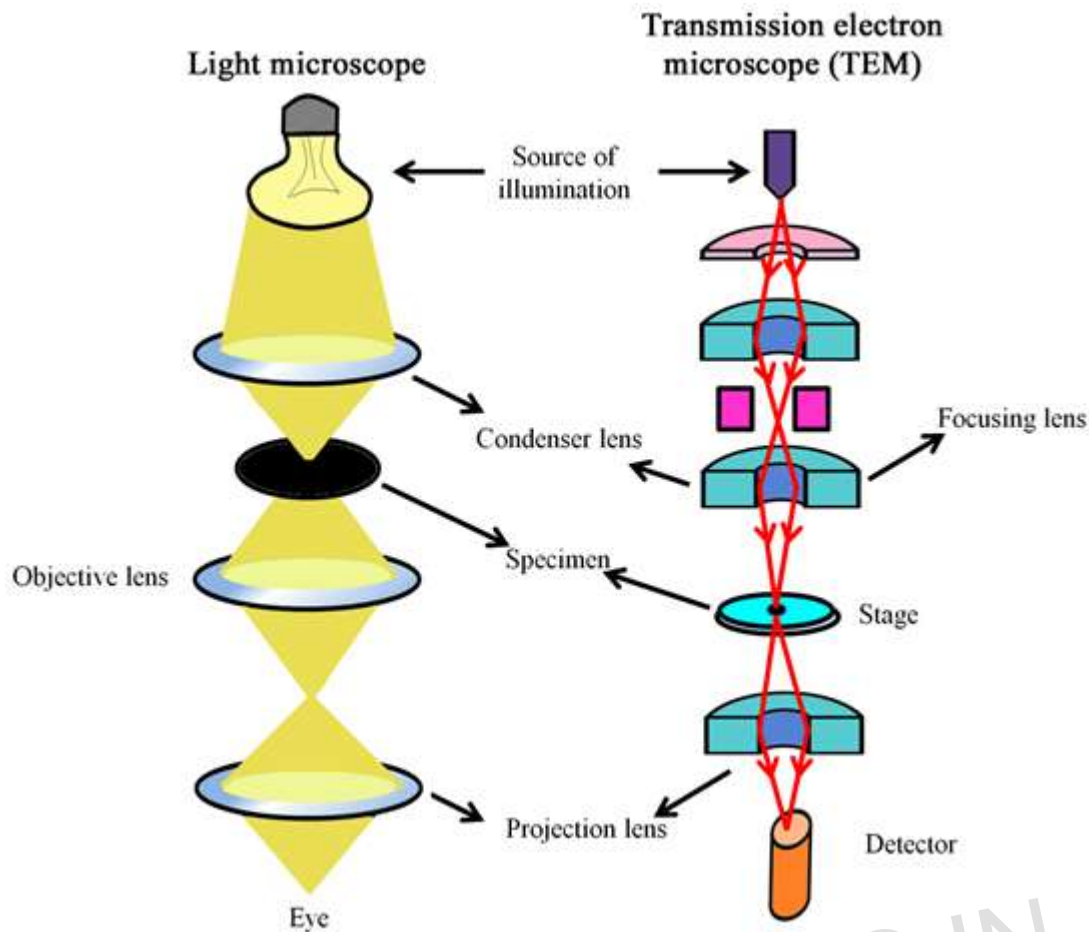
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A secondary electron detector is biased with positive potential to attract the low energy secondary electrons. Detector for backscattered electrons is not biased; the high energy backscattered electrons strike the unbiased detector. As backscattered 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.

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

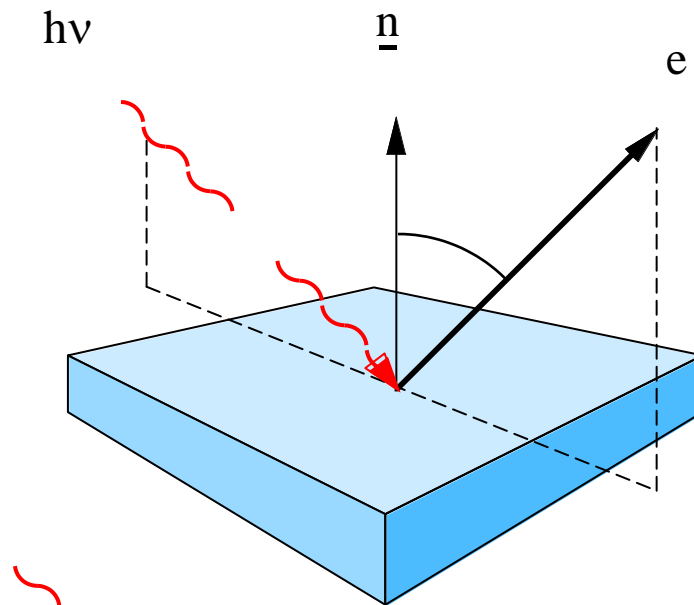
Transmission electron microscopes usually have thermionic emission guns and electrons are accelerated anywhere between 40 – 200 kV potential. However, TEM with >1000 kV acceleration potentials have been developed for obtaining higher resolutions. Owing to their brightness and very fine electron beams, 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 ( $\Phi$ ) of the sample (typically a few electron-volts), then it will leave the surface and can be detected.

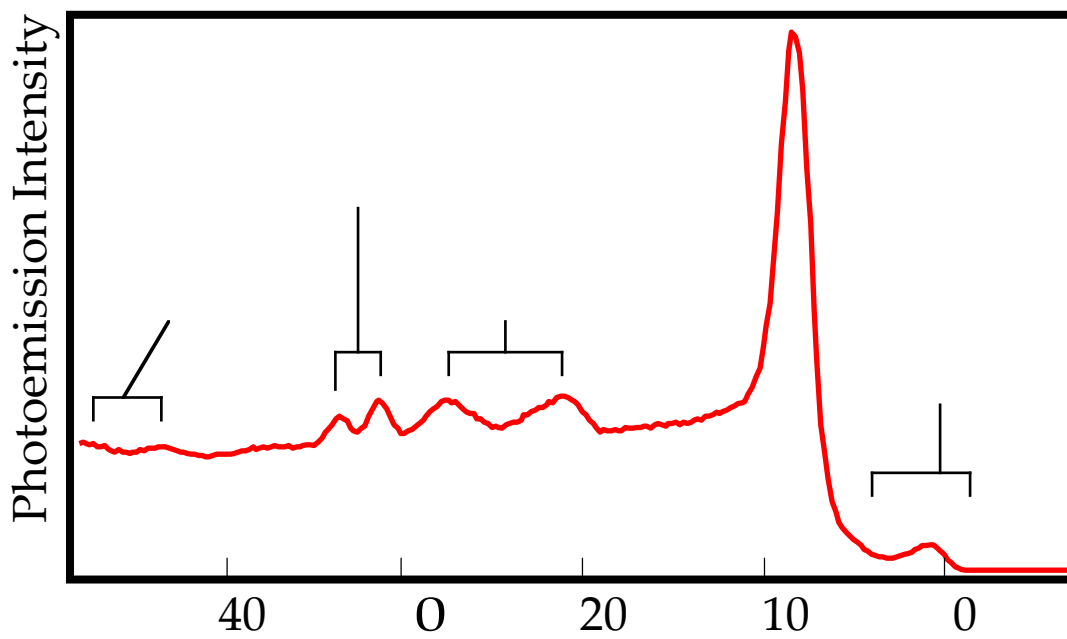


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By absorbing a photon, an electron is kicked from a low energy state ( $\circ$ ) inside an atom into a higher energy state ( $\bullet$ ) in which it is free to move through the sample.

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 ( $\Phi$ ) of the sample, then we can calculate the binding energy of the electron.



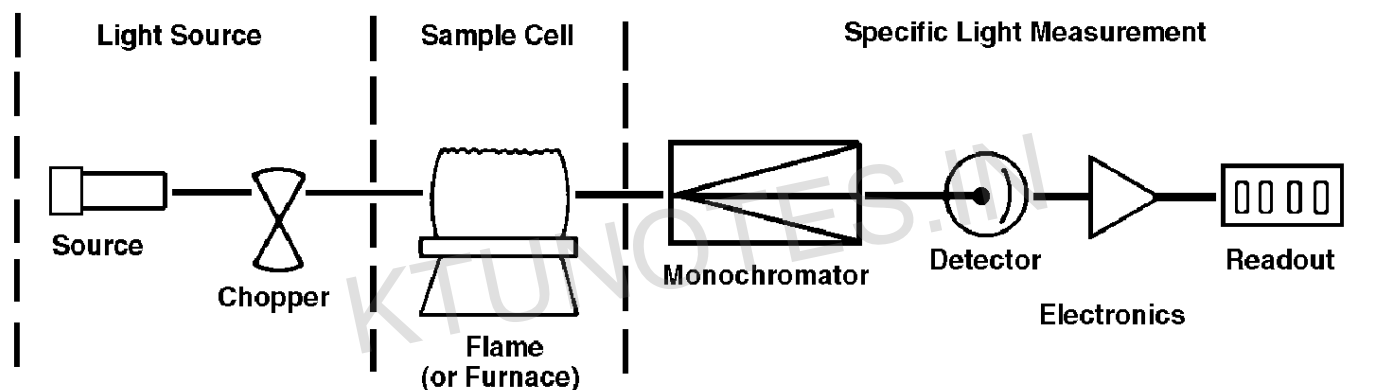
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### Binding Energy I eV

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.

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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.

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