UNIT I – INTRODUCTION TO CRYSTALLINE MATERIALS

Part A - 2 marks

1. **Define Solid solution.**
   - A solid solution is a homogeneous mixture of two different kinds of atoms in a solid state and having a single crystal structure.
   - A solid solution is formed by mixing a foreign element B (called an impurity or solute) with a perfect crystalline element A (called the host or solvent) such that single phase is maintained.

2. Name the two kinds of solid solutions.

The two kinds of solid solutions are
- Substitutional solid solutions.
- Interstitial solid solutions.

3. How the substitutional solid solutions are formed?

When the solute atoms replace solvent atoms, substitutional solutions are formed.
Substitutional solid solutions are of two types: They are
- Arranged or ordered substitutional solid solution.
- Random or disordered substitutional solid solution.

Example : Cu – Ni System.

4. How the Interstitial solid Solutions are formed?

When the Solute atoms are small enough to occupy the space between the Solvent atoms, interstitial Solutions are formed.
Example : Fe – C System.

5. What are the factors governing Solid solubility? (Or) State Hume Rothery's rules. (Or) State the conditions under which two metallic elements will exhibit unlimited solid solubility.

To exhibit unlimited solid solubility, the solute and solvent elements should obey the following general rules of Hume Rothery.
i. Size factor (atomic radius)
ii. Crystal structure
iii. Valency
iv. Electro negativity

6. Write principles of solidification.

Solidification is an important processing technique used in the manufacturing of materials. The solidification of crystalline materials requires two steps:

1. Ultra-fine crystallites, known as the nuclei of a solid phase, forms from the liquid.
2. The ultra-fine solid crystallites begin to grow as atoms from the liquid are attached to the nuclei until no liquid remains.

7. What are the critical Factors Influencing Solidification?

A variety of factors influence the process of solidification:

Heat Transfer	The rate at which heat is transferred away from the liquid influences the speed of solidification.
Composition	The elements present in the liquid and their proportion can affect the freezing point, leading to differences in solidification.
Pressure	Higher pressures can raise the freezing point, affecting the temperature at which solidification takes place.

8. What are the importance of Solidification in Engineering Processes?

Solidification plays a crucial role in several engineering processes:

- In Metal Casting: Metals are first melted and then solidified into desired shapes.
- In Welding: The solidification principle is used to bond materials together.
- In Crystal Growth: Solidification aids in the production of single crystals for semiconductors, optical devices, and other applications.

9. What is nucleation in crystallization?
Nucleation involves the appearance of very small particles, or nuclei of the new phase (often consisting of only a few hundred atoms), which are capable of growing. During the growth stage these nuclei increase in size, which results in the disappearance of some (or all) of the parent phase.

10. What are the types of nucleation? (OR) What is homogeneous and heterogeneous nucleation?
Based on the site at which nucleating events occur, nucleation can be divided into two types:

(i) Homogeneous nucleation: nuclei of the new phase form uniformly throughout the parent phase.

(ii) Heterogeneous nucleation: nuclei form preferentially at structural inhomogeneities such as container surfaces, insoluble impurities, grain boundaries, and dislocations.

11. What is a single crystal?

A crystalline material in which the crystal lattice is found to be continuous throughout the material is called a single crystal. It is also called as monocrystal. The entire solid consists of only one crystal due to non-interrupted repetition of unit cell in all three dimensions. The single crystals are produced artificially from their vapor (or) liquid state.

12. What is a Poly crystal?

The crystalline solid consists of an aggregate of many small crystals (or) grains which are separated by well-defined grain boundary is called a poly crystal. The grains which are separated by grain boundaries have random crystallographic orientations with size ranging from nanometres to millimetres. The poly crystals are produced through sol-gel, solid state reaction, hydrothermal and combustion methods.

13. Define critical radius.

The critical radius (r*) is the minimum size of a crystal that must be formed by atoms clustering together in the liquid before the solid particle is stable and begins to grow.

14. Mention basic conditions for growing crystal.

1. Achievement of super saturation or super cooling.
2. Formation of crystal nucleus of microscopic size.
3. Successive growth of crystals to yield distinct faces.

15. Mention a few solution and melt growth techniques for the growth of the crystals.

Solution growth technique:
Gel Growth
Hydrothermal growth
Growth from aqueous solution
Flux growth

Melt growth technique:
Bridgman Technique
Czochralski method (Crystal pulling)

16. What is the principle used in Czochralski method?

"Crystal pulling from the melt" is the principle used in Czochralski method. Here the material is melted over the monocrystalline seed and is rotated. Further with the help of a pull rod, it is slowly drawn upwards and hence the melt freezes on the crystal and thus the crystal grows.

17. Define Phase.

Phase may be defined as a homogeneous portion of a system that has uniform physical and chemical characteristics. Every pure material is considered to be a phase. If more than one phase is present in a given system, each will have its own distinct properties, and a boundary separating the phases will exist across which there will be a discontinuous and abrupt change in physical and/or chemical characteristics.

18. State Gibb's Phase rule.

Gibb's Phase rule is stated as the number of phases present in any alloy depends upon the number of elements of which the alloy is composed.

From thermodynamics consideration of equilibrium, J.W.Gibbs has derived the following phase rule:

F = C – P + N

Where, F = Degrees of freedom of system
C = Number of components forming the system
P = Number of phases present in the system
N = Number of Variables (Pressure, Temperature, Composition)

19. Give the advantages of Phase rule.

The followings are the advantages of Phase rule:

- It provides a convenient method for classification of equilibrium states of a system with the help of phases, components and degrees of freedom.
- It predicts the behaviour of system with changes in intensive variables such as temperature, pressure and composition.
- It indicates that different systems having the same number of degrees of freedom behave in the same manner.
- It is applicable to macroscopic system and therefore, information about the molecular structure is not necessary.
- It takes no account of nature of the reactants or products in phase.
- It is applicable to physical as well as chemical equilibria.

20. What is Phase diagram and mention its types?

Phase diagram is a graphical representation of physical states present in materials at various temperature, pressure and compositions.

The types of Phase diagram based on number of components:

i. Unary (One component system)
ii. Binary (Two component system)
iii. Ternary (Three component system)
iv. Quaternary (Four component system) etc.

21. What is lever rule?

The lever Rule is employed to find the relative amount (as a fraction or as a percentage) of the phase present at equilibrium. It works on the fundamental principle of a lever.

The Tie line, an isothermal line through the alloy's position on the phase diagram when it is in two phase field, intersecting the two adjacent solubility curves is drawn and the phase percentage is calculated using the below expression

$$phase\ \% = \frac{opposite\ arm\ of\ the\ lever}{total\ length\ of\ the\ tieline} \times 100$$

22. What is binary phase diagram and mention various types of binary phase diagrams?

The phase diagrams which are based on two-component system are called binary phase diagrams.

Types:

Isomorphous system: This type of system shows complete solubility of each other in the solid phase as well as liquid phase. Eg. Cu-Ni, Au-Ag, Au-Cu, Mo-W, Mo-Ti etc.

Type I eutectic system: The two components are completely soluble in the liquid state but completely insoluble in each other in solid phase. Eh. Pb-As, Bi-Cd, Au-Si.

Type II eutectic system: The two components are completely soluble in a liquid state and partially soluble in solid phase. Eg. Pb-Sn, Cu-Ag, Cd-Zn, Sn-Bi.

Eutectoid system: One solid phase transform to a mixture of two solid phases. Eg. Ag-Cd, Al-Mn, Au-Zn, Cu-Zn.

Peritectic system: Two-phase mixture of a liquid and a solid transform to a single-phase solid. Eg. Ag-Pt.

23. What is Eutectic Reaction and Peritectic reaction?

Eutectic reaction:

- Two metals that are completely soluble in Liquid state and partly or insoluble in the solid state is called Eutectic reaction.
- In Eutectic reaction, upon cooling, a liquid phase transform isothermally and reversibly to a two solid phases having a different composition.

Liquid → Solid 1 + Solid 2

Peritectic reaction:

In Peritectic reaction, upon cooling, a solid and a liquid phase transform isothermally and reversibly to a solid phase having a different composition.

Liquid +Solid 1 → Solid 2

24. What is Eutectoid Reaction and Peritectoid reaction?

Eutectoid reaction is an isothermal reversible reaction in which one solid phase transforms into two intimately mixed new solid phases, upon cooling.

Solid 1→Solid 2 + Solid 3

Example: Cu - Zn system, Cu - Sn system, Al - Mn system, Cu - Be system.

Peritectoid reaction is an isothermal reversible reaction in which two solid phases transform into a third solid phase, upon cooling. The Peritectoid reaction can be written as
Solid 1 + Solid 2 → Solid 3
Example: Ni-Zn system, Fe-Nb system, Cu-Sn system, Ni-Mo system

25. What do you mean by liquidus and solidus in phase diagram?

The phase boundary between liquid phase and the two phase region is called liquidus. The phase boundary between solid and two phase region is called solidus.

26. Mention some important reactions in phase diagram.

Some important reactions in phase diagram are
- Eutectic reaction
- Peritectic reaction
- Eutectoid reaction
- Peritectoid reaction

27. Define invariant reaction.

The reaction which is having zero degree of freedom is called invariant reaction.
Example: Eutectic reaction

28. What are types of steel in iron – carbon phase diagram?
Steel is an alloy of iron with 0.008% to 2% of carbon. Steel is further classified into 3 types. They are
- Eutectoid steel
- Hypoeutectoid steel
- Hypereutectoid steel

29. Differentiate eutectoid, hypoeutectoid and hypereutectoid steels?

- The steels which contain 0.8% carbon are called eutectoid steels.
- Steels which contain less than 0.8% carbon are known as hypoeutectoid steels.
- Steels which contain more than 0.8% carbon are known as hypereutectoid steels.

30. What is X-ray diffraction?

X-ray diffraction (XRD) is a versatile non-destructive analytical technique used to analyze physical properties such as phase composition, crystal structure and orientation of powder, solid and liquid samples.

31. Define Bragg's law.

According to Bragg's law

$$2d\ sin\theta = n\lambda$$

here,

d is the space between the diffracting planes,

θ (theta) is incident angle,

n is integer,

and , λ is beam wavelength.

PART – B and C

1. What are solid solutions? How are they classified? Explain each in detail.
2. What is known as nucleation? Explain homogeneous and heterogeneous nucleation processes in crystal growth.
3. Explain the transformation of liquid to crystals by nucleation and growth processes.
4. Explain free energy changes in heterogeneous nucleation with diagram.
5. With the help of a neat diagram explain Czochralski technique for crystal growth.
6. Explain isomorphous system with one example.
7. Explain tie-line rule and lever rule.
8. Explain iron-carbon phase diagram and explain different phases formed concerning change in composition and temperature.
9. Explain invariant reactions in iron-carbon phase diagram.
10. Write a detailed note on crystal characterization using X-ray diffraction technique.

UNIT II- ELECTRICAL AND MAGNETIC PROPERTIES OF MATERIALS

Part A – 2 Marks

1. **Define electrical conductivity.**
The coefficient of electrical conductivity is defined as the quantity of electricity flowing per unit area per unit time maintained at unit potential gradient. Its unit is $\Omega^{-1}m^{-1}$.
$$\boldsymbol{\sigma = Ne\mu}$$
2. **Give the microscopic form of ohm's law in a metallic conductor. Whether the Ohm's law is true at all temperatures.**
$$\boldsymbol{J = \sigma E}$$
Where J is the current density (number of electrons flowing per second through unit area), σ is the electrical conductivity and E is the electric field intensity.
The ohm's law is not true at all temperatures in a conductor, since the resistance of a conductor varies with temperature in a complicated manner at different range of temperatures.

3. **Define thermal conductivity.**
Thermal conductivity is defined as the ratio of quantity of heat energy conducted per unit area of cross section per second to the temperature gradient.
$$\boldsymbol{K = \frac{nv^2 k_B \tau}{2}}$$
4. **Define drift velocity ϑ_d. How is it different from thermal velocity of an electron.**
The drift velocity is defined as the average velocity acquired by an electron in the presence of an electric field $\vartheta_d = \frac{J}{ne}$.
The thermal velocity is random in nature, gained by charge carriers by virtue of its temperature. Drift velocity is directional one and is very small

5. **Define relaxation and collision time of free electrons in a metal.**
Relaxation time is defined as the time taken by an electron to reach equilibrium position from its disturbed position in the presence of electric field. The collision time is defined as the average time taken by an electron between two successive collisions. For an isotropic collision, the relaxation time and collision time are equal.

6. **State Widemann – Franz law.**
The ratio between thermal conductivity and electrical conductivity of a metal is a constant at a given temperature.
i.e., $\frac{K}{\sigma T} = L$. Where K and σ is thermal conductivity and electrical conductivity respectively.
L is a constant known as Lorentz number, the experimental value of Lorentz number is L = 2.3 $\times 10^{-8}$ WΩK^{-2} and the theoretical value of Lorentz number is L = 1.11 $\times 10^{-8}$ WΩK^{-2}.

7. **State a few postulates/assumptions/Salient features of classical free electron theory.**
   i. In metals there are large number of free electrons moving freely in all possible directions.
   ii. These free electrons behave like gas molecules in a container obeying the laws of kinetic theory of gases.

iii. The energy associated with each electron at a temperature T is given by $\frac{3}{2}k_BT$. It is related to kinetic energy as $\frac{3}{2}k_BT = \frac{1}{2}mv_{Th}^2$. Where v_{Th} is the thermal velocity and k_B is Boltzmann constant.
iv. The electron velocities in metal obey the Maxwell-Boltzmann distribution of velocities.
v. The free electrons move in a uniform potential field due to ions fixed in the lattice.
vi. When an electric field is applied to the metal the free electrons are accelerated. The accelerated electrons move in opposite direction of the applied field.
vii. The electric conduction is due to the free electrons only.

8. What are the failures of classical free electron theory?

i. It predicted that the value of specific heat capacity of metal is 4.5R. But experimentally it is about 3R only.
ii. The ratio between thermal conductivity and electrical conductivity is not constant at low temperatures.
iii. The value of Lorentz number determined using classical free electron theory (1.12×10^{-8} WΩ K^{-2}) is only half of the experimental value i.e. 2.44×10^{-8} WΩ K^{-2}.
iv. Classical theory states that all the free electrons absorb the supplied energy. But, that is not the case.
v. The electrical conductivity of semiconductors and insulators cannot be explained by this theory.
vi. The photo electric effect, Compton effect, and the black body radiation cannot be explained on the basis of classical free electron theory.
vii. The susceptibility of paramagnetic material is inversely proportional to temperature. But, the experimental results show that paramagnetism of metal is independent of temperature. Moreover, ferro magnetism cannot be explained by this theory.

9. What are the assumptions of Quantum Free Electron Theory?
i. The free electrons are fully responsible for the electrical conduction.
ii. The free electron is free to move anywhere within the crystal.
iii. The loss of energy due to interaction of the free electron with the other free electron, or positive ion core or wall of the container is negligible.
iv. The free electron behaves as a wave. It has to obey the quantum concepts.
v. The velocity and the energy distribution of the free electrons are governed by the Fermi-Dirac distribution function.

10. What are the merits of quantum free electron theory?
i. It explains the specific heat capacity of metals.
ii. It explains photo electric effect, Compton Effect, black body radiation and Zeeman effect.
iii. It gives the correct mathematical expression for the thermal conductivity of metals.

iv. It explains the superconducting property.

11. What are the demerits of quantum free electron theory?

i. This theory fails to distinguish between metal, semiconductor and insulator.

ii. It also fails to explain the positive value of Hall Co-efficient.

12. What is Fermi Function?

The Fermi function f(E) gives the probability that a given available electron energy state will be occupied at a given temperature.

$$f(E) = \frac{1}{e^{(E-E_F)/k_BT} + 1}$$

Where,

E is energy of energy level under consideration,

E_F is Fermi energy level,

T is the temperature,

k_B is Boltzmann constant.

13. What is Fermi energy? What is its importance?

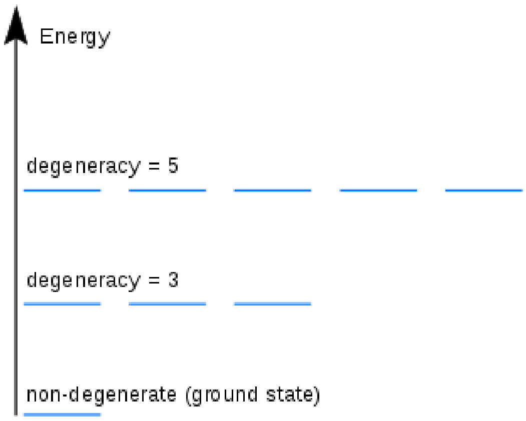
Fermi level is the maximum energy level occupied by the electrons at absolute zero degree kelvin. The Fermi level at absolute zero is also known as Fermi energy.

14. Define density of states. What is its use?

Density of states is defined as number of energy states available per unit volume between the energy levels E and E + dE. It is used to calculate the number of charge carriers per unit volume of the solid.

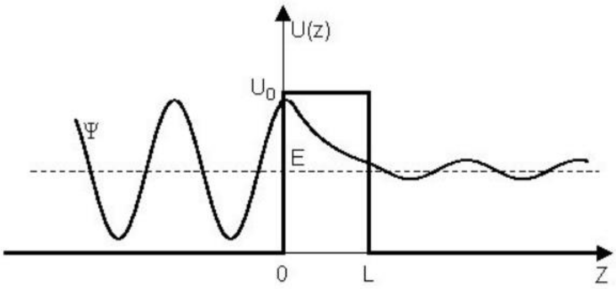
15. What are degenerate states?

Quantum states with the same sharply defined energy are known as degenerate states. Number of states having same energy is the degree of degeneracy.



16. What is tunnelling effect?

Classically, when a particle is incident on a barrier of greater energy, reflection occurs. When described as a wave, the particle has a probability of existing within the barrier region, and even on the other side of it. This effect is the tunnel effect or quantum tunnelling.
In the figure below wave with wave function Ψ can penetrate the barrier of potential U_0 despite its energy E being lesser than U_0.



17. Define energy bands in solids?

In atoms, electrons are filled in respective energy orbits following Pauli's exclusion principle. Two atomic orbitals combine to form a molecular orbit and many such atomic orbitals in a solid stack up to form an energy continuum called energy band.

18. Define valence band, conduction band, and forbidden band/band gap.

Valence band

The energy band that consists of valence electrons energy levels, is known as the valence band. The valence band is present below the conduction band and the electrons of this band are loosely bound to the nucleus of the atom.

Conduction band

The energy band that consists of free electrons energy levels, is known as the conduction band. For electrons to be free, external energy must be applied such that the valence electrons get pushed to the conduction band and become free.

Forbidden band

The energy gap between the valence band and the conduction band is known as the forbidden band or forbidden gap. The electrical conductivity of a solid is determined by the forbidden gap and also the classification of the materials as conductors, semiconductors, and insulators.

19. What is tight binding approximation/model?

Tight binding model is one of the methods for band structure calculation.

When atoms are far apart, all the bound electrons have fixed energy levels. As atoms are brought closer to each other, outer shell electrons overlap with each other. The energy levels of these outer shells are forced to split into energy levels above and below the energy levels of these electrons to accommodate the outer electrons without violating Pauli's exclusion principle.

As the distance keeps on decreasing, more inner shell electron levels overlap and split.

It is valid for the core electrons of most solids and all the electrons in an insulator.

20. What is effective mass?

A particle's effective mass (often denoted m*) is the mass that it seems to have when responding to forces.

$$m^* = \frac{1}{\frac{1}{\hbar^2}\frac{d^2E}{dk^2}}$$

21. What are holes?

Holes are the vacant sites in the valence band of a solid. These will behave like positive charge carriers having the mass of electron in the presence of applied electric field.

22. What are the sources of electrical resistance in metals?

The cause for electrical resistance is the electron scattering and the cause for electron scattering is the non-periodicity of the lattice potentials. The causes for non-periodicity of lattice potentials are:

(i) impurities in crystals,
(ii) crystal defects (or imperfections) and
(iii) thermal vibrations.

23. Distinguish between conductor and semiconductor on the basis their electrical conductivity.

Conductor has electrical conductivity of 10^4 to 10^9 $ohm^{-1}m^{-1}$ and semiconductor has electrical conductivity of 10^3 to 10^4 $ohm^{-1}m^{-1}$. For conductors, the electrical conductivity is decreased with respect to addition of impurities and increase of temperature due to decrease in mean free path. But in semiconductors, the electrical conductivity is increased with respect to addition of impurities and increase of temperature due to increase of charge density.

24. Aluminium has three valence electrons and copper has one valence electron. Why do we have large electrical conductivity for copper than Aluminium?

Based on quantum electron theory, even though aluminium has three times as many conduction electrons as copper, the area of the Fermi surface in aluminium is about the same in copper. But the number of uncompensated electrons in the Fermi surface of copper is more than the number of uncompensated electrons in the Fermi surface of aluminium. Since the value of the electrical conductivity depends on the number of compensated electrons, copper has higher electrical conductivity than aluminium.

25. What are magnetic materials?
The materials which can be magnetized and are attracted towards a magnet are called magnetic materials.

26. What is a magnetic dipole?
Any two opposite poles separated by a suitable distance constitute a dipole. A magnet is said to be a magnetic dipole. It has north and south poles. The distance of separation is the length of the magnet.

27. Define Magnetic dipole moment.
It is defined as the product of magnetic pole strength and length of the magnet. It is represented by μ. If m is the magnetic pole strength and l is the length of the magnet then,

$$\mu = m.l$$

28. What are magnetic lines of force?
The magnetic field in magnetic material is studied by drawing the magnetic lines of forces. The magnetic lines of forces are also called as magnetic flux. It originate from north pole and end at south pole.

29. What is magnetic flux density?
The magnetic lines of force passing through the unit area of cross section is known as the magnetic flux density. It is represented by B. Its unit is WBm^{-2}.

The magnetic flux density is given by $B = \frac{\phi}{A}$
Where, ϕ is the magnetic flux and A is the area of cross section.

30. What is magnetic field strength?
The magnetic field strength is the force experienced by a unit north pole placed in the magnetic field region. It is represented by H. Its unit is Am^{-1}.

31. Define the term magnetization.
The magnetic moment per unit volume is known as magnetization. It is represented by M and its unit is Am^{-1}.

32. What is magnetic susceptibility?
The ratio of the magnetization to the magnetic field strength is known as magnetic susceptibility. It has no unit and it is represented byχ.

$$\chi = \frac{M}{H}$$

33. What is magnetic relative permeability?

The ratio of the permeability of the medium to the permeability of a free space is known as magnetic relative permeability. It is represented by μ_r. The value is given by $\mu_r = \frac{\mu}{\mu o}$. Here μo is the permeability of free space and is equal to $\mu o = 4\pi \times 10^{-7} H\, m^{-1}$.

34. What is Bohr Magneton?

Bohr Magneton is the magnetic moment contributed by an electron when it is in first orbital.

$$\mu_L = n\frac{e\hbar}{2m}$$

when n=1 $\mu_L = \mu_B$

1 Bohr magneton $\mu_B = \frac{eh}{2m} = 9.27 \times 10^{-24} J/T$

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35. On the basis of spin how the magnetic materials are classified

The magnetic materials are classified as,

- Diamagnetic materials do not have any unpaired electron.
- Paramagnetic materials have few unpaired electron spins of equal magnitudes.
- Ferromagnetic materials have many unpaired electron spins with equal magnitudes.
- Anti-Ferromagnetic materials have equal magnitude of spins but in anti-parallel manner.
- Ferri-magnetic materials have spins in anti-parallel manner but with unequal magnitudes.

36. What do you understand by the term "magnetic domains" and "domain walls"?

Magnetic domains are the small regions in a ferromagnetic material which has a group of atoms. These atoms can be completely magnetized by favourable exchange spin-spin interaction. The walls of these small regions (or) domains are called domain walls.

37. Distinguish among dia, para and ferro magnetism.

S.No	Diamagnetism	Paramagnetism	Ferromagnetism
1.	There are no permanent dipole moment	There exists a permanent dipole moment	There are enormous amount of permanent dipole moment
2.	The electrons align perpendicular to the direction of the applied magnetic field (weak magnets)	The electrons align parallel to the direction of the applied magnetic field (strong magnets)	The electrons which are already aligned parallel will reorient itself along the field direction (very strong magnets)
3.	The magnetic flux lines are repelled away	The magnetic flux lines passes through the material	The magnetic flux lines are highly attracted towards the centre of the material

4.	Magnetic susceptibility is negative	Magnetic susceptibility is positive and small	Magnetic susceptibility is positive and large
5.	Magnetic permeability is less than 1.	Magnetic permeability is greater than 1.	Magnetic permeability is very much greater than 1.
6.	Ex: Gold, Silicon, water etc.	Ex: Platinum, Aluminium, chromium etc.	Ex: Iron, Nickel, Cobalt etc.

38. Give the origin of magnetic moment in magnetic materials.

The magnetic moment originates from the orbital motion and spinning motion of electrons in atoms. Particularly ferromagnetism is mainly due to spin-spin interaction of unpaired electrons in the ferromagnetic atoms.

39. State Curie-Weiss law.

$$\chi = \frac{\boldsymbol{C}}{\boldsymbol{T} - \boldsymbol{\theta}}$$

where,
C is Curie constant, T is absolute temperature and $\boldsymbol{\theta}$ is Curie temperature.

It determines the susceptibility of the magnetic materials in terms of temperatures ie., If the temperature is less than curie temperature, a paramagnetic material becomes diamagnetic.

If the temperature is greater than Curie Temperature, a ferromagnetic material becomes paramagnetic material.

40. Classify Ferromagnetic materials based on their spin type.

Ferro magnetic materials have many unpaired electron spins with equal magnitudes. Based on that, they are classified as

- Anti Ferro magnetic materials have equal spin magnitude but in anti parallel manner.
- Ferromagnetic materials have anti parallel spins with unequal magnitudes.

41. Explain exchange interaction.

Exchange interaction is a quantum mechanical effect originating due to Pauli's exclusion principle and electrostatic interaction. Due to exchange interaction, two neighbouring spins in a solid are coupled together with an exchange energy given by:

$$E_{ex} = -2\boldsymbol{J}\boldsymbol{S}_i \cdot \boldsymbol{S}_j$$

$\boldsymbol{S}_i$ and $\boldsymbol{S}_j$ are spin angular momentum vectors of two electrons i and j.

42. Distinguish between Curie and Pauli Paramagnetism.

Curie Paramagnetism	**Pauli Paramagnetism**
Applies to localised electrons.	Applies to electrons in bands.
Much higher susceptibility because all the electrons are allowed to change the spin.	Much weaker susceptibility because only the electrons near the Fermi surface can change its spin to align with the magnetic field.
Occurs in materials with paired electrons.	Occurs in materials with unpaired electrons where electron spin interacts with magnetic field.
More significant at higher temperatures.	Dominant at low temperatures.
Results in stronger magnetic field.	Results in weaker magnetic field.
Can be explained in the constraints of classical mechanics.	Require Fermi Dirac statistics and quantum nature of electrons.

43. What is A.C Josephson effect?

When two superconducting materials are separated by an insulator of very few thicknesses and are connected to a DC power, then an AC microwaves are produced at the junction. This effect is called AC Josephson effect.

44. What is D.C Josephson effect?

When two superconducting blocks of different materials like aluminum and tin are kept at liquid helium temperature and separated by a small gap of the order of few Å and are connected externally by a wire, a direct current flows in the external circuit. This is called D.C Josephson effect.

45. Distinguish between D.C and A.C Josephson Effect.

S.No.	**D.C Josephson effect**	**A.C. Josephson effect**
1	When two super conducting materials are separated by an insulator of very few thickness and are connected by a wire, a d.c. current flows in the external circuit	When two super conducting materials are separated by an insulator of very few thickness and are connected to a d.c. power, then a.c. microwaves are produced at the junction
2	The current persists for a longer time.	The current persists only for a short time.

46. What are SQUIDS? What are their uses?

Superconducting Quantum Interference Devices (SQUIDS) are based on the flux quantization in a superconducting ring and is a double junction quantum interferometer formed from two Josephson junctions mounted on a superconducting ring. SQUID sensors have high sensitivity at low temperatures and are used to detect defects in heart and brain through magnetocardiography and magnetoencephalography.

47. What do you infer from the word magnetoresistance?

- Magnetoresistance is the tendency of the material (preferably ferromagnetic) to change the value of its electrical resistance in an externally applied magnetic field.
- Observed in multilayer composed of alternating ferromagnetic and non magnetic conductive layers.
- The effect is based on the dependence of electron scattering on the spin orientation.

48. Explain the relation between electrical resistance and magnetic moments of GMR devices.

Change in electrical resistance depends on whether the magnetization of adjacent ferromagnetic layers are in parallel or in antiparallel alignment.
For parallel alignment overall resistance is relatively low.
For anti-parallel alignment resistance is relatively high.

49. Mention application of GMR.

GMR can be used in

- Magnetic field sensors, which are used to read data in hard disc drive.
- Biosensors.
- Micro electro-mechanical systems.
- Magnetoresistive random access memory (MRAM) as cells that store one bit of information.

PART – B and C

1. Deduce a mathematical expression for electrical and thermal conductivity of a conducting material based on free electron theory.

2. What is density of states? Derive an expression for the density of states. Using density of states, obtain an expression for the carrier concentration in metals.

3. Describe the Fermi-Dirac distribution function and explain the effect of temperature on the Fermi function and hence derive an expression for the carrier concentration of metals.

4. What is meant by exchange energy? Explain the origin of ferromagnetism using exchange interaction concept.

5. Explain dia, para and ferromagnetism.

6. Write short note on: SQUID and GMR devices.

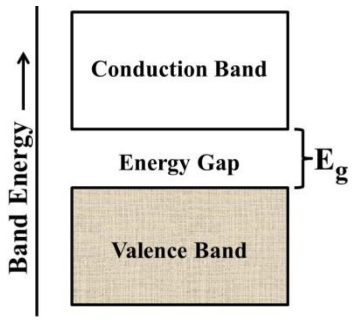
UNIT III SEMICONDUCTORS AND TRANSPORT PHYSICS

Part - A (2 Marks)

1. **What is a semiconductor?**

Semiconductor is a special class of material which behaves like an insulator at 0 K and acts as conductor at temperature other than 0 K. Its resistivity lies in between a conductor and an insulator.

2. **Draw the energy band diagram of a semiconductor.**



Energy band diagram of a semi-conductor

3. **What are the properties of semiconductors?**

- The resistivity of a semiconductor is less than an insulator but higher than a conductor.
- Semiconductors show a negative temperature coefficient of resistance. The resistance of the semiconductors decreases as the temperature increases and vice-versa.
- At 0K, semiconductors behave as insulators. As the temperature is increased it works as a conductor.
- The conductivity of the semiconductors increases when impurities are added. The process of adding impurities to semiconductors is called doping.

4. **Mention a few advantages of semiconducting materials.**

- Electronic properties of semiconductors can be controlled to suit our requirement.
- They are smaller in size and light weight.
- They can operate at smaller voltages (of the order of few mV) and require less current (of the order of pA or mA), therefore, consume lesser power.
- Almost no heating effects occur, therefore these devices are thermally stable.
- Faster speed of operation due to smaller size.
- Fabrication of ICs is possible.

5. **What is the meaning of band-gap of a semi-conductor?**

Band-gap (or) energy gap of a semi-conductor is the region of energies, which are not allowed to occupy by the electron of that material. It is equal to the energy difference between the minimum energy of conduction band and the maximum energy of valence band of that material. But in a band gap the added impurity atoms can have their energy levels.

6. What is Fermi level in a semi-conductor?

Fermi level in a semiconductor is the energy level situated in the band gap of the semiconductor. It is exactly located at the middle of the band gap in the case of intrinsic semiconductor. Thus it is a reference energy level from which the maximum energy the valence band and minimum energy of the conduction band are referred.

7. Differentiate elemental and compound semiconductor.

Elemental semiconductor	Compound semiconductor
They are made up of single-element.	They are made up of compounds. Group II with group VI and Group III with group V, and group IV with group IV.
They are known as indirect band gap semiconductors.	They are also known as direct band gap semiconductor
Electron hole recombination takes place through traps.	Electron hole recombination takes place directly.
Life time of charge carriers is more due to indirect recombination.	Life time of the carriers is less due to direct recombination.
Heat energy is produced during recombination	No excess heat is generated.
Light photons are not directly emitted, instead, phonon emission followed by photon takes place.	Recombination is radiative and photon is emitted directly.
They carry more current.	They carry less current.
They are used for making diodes and transistors.	They are used for making LED's and LASER (optoelectronic devices)

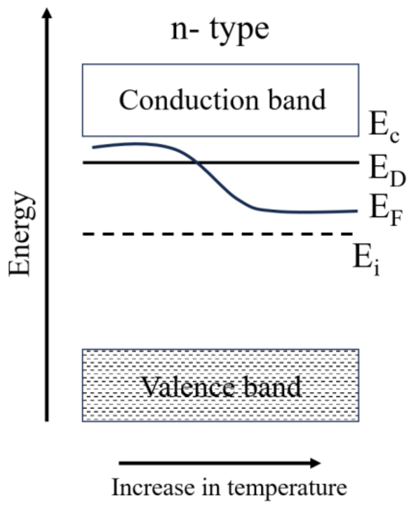
8. What are the differences between intrinsic and extrinsic semiconductor?

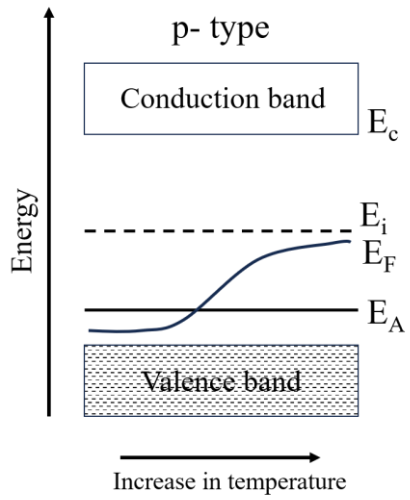
S.No	Intrinsic Semiconductor	Extrinsic Semiconductor
1.	Semiconductor in pure form is called intrinsic semiconductor.	Semiconductors that are doped with impurities are called extrinsic semiconductors.
2.	Here the charge carriers are produced only due to the thermal agitation.	Here, the charge carriers are produced due to impurities.
3.	Examples: Si, Ge, etc.	Examples: Si and Ge doped with Al, In, P, As, etc

9. What is an n-type and p-type semiconductor?

When a small amount of pentavalent impurity is added to a pure semiconductor, it becomes an n-type semiconductor and when a trivalent impurity is added it becomes p-type semiconductor.

10. Sketch the variation of Fermi level with temperature in the case of p-type semi-conductor and n-type semiconductor.

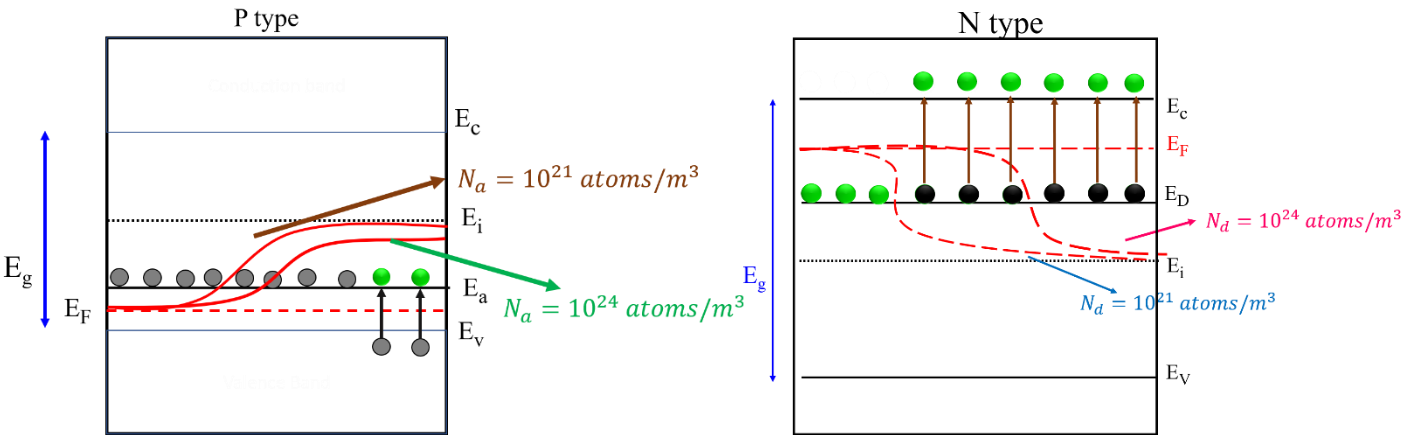




11. What is meant by doping and doping agent?

The technique of adding impurities to a pure semiconductor is known as doping and the added impurity is called doping agent.

12. Sketch the effect of carrier concentration on n and p-type semiconductors?



Variation of Fermi level in extrinsic semiconductor as a function of carrier concentration

13. Explain the concept of hole in semiconductor.

In intrinsic semiconductor, charge carriers are created due to breaking of covalent bonds. When a covalent bond is broken, an electron escapes to the conduction band leaving behind an empty space in the valence band. This missing electron is called a hole.

14. What is meant by donor and acceptor energy level?

When an intrinsic semiconductor is doped with pentavalent impurity, a new energy level is introduced just below the conduction minima of intrinsic semiconductor to accommodate new electrons. This level is rich in electrons and is called donor level.
When an intrinsic semiconductor is doped with trivalent impurity, an extra energy level rich in holes is introduced just above the valence band maxima. This level is acceptor energy level.

15. Define Mobility.

It is defined as the velocity of a charge carrier per unit electrical field strength.

$$\mu = \frac{v_d}{E}$$

16. Define drift velocity.

When an electrical field is applied in a semiconducting material, the free charge carriers such as free electrons and holes attain drift velocity v_d. The drift velocity attained by the carriers is proportional to the electrical field strength E.

$$v_d \propto E$$
$$v_d = \mu E$$

where μ is a proportionality constant and it is known as the mobility of the charge carrier.

17. Define drift current.

The electric current produced due to the motion of charge carriers under the influence of an external electric field is known as drift current.

18. Define diffusion current.

The non-uniform distribution of charge carriers creates the region of uneven concentrations in the semiconductor. The charge carriers move from the regions of higher concentration to the regions of lower concentration. This process is known as diffusion. The current is known as diffusion current.

19. What is ohmic contact?

An ohmic contact is a type of metal semiconductor junction. It is formed by a contact of a metal with a heavily doped semiconductor. When the semiconductor has a higher work function than that of metal, then the junction formed is called the Ohmic junction.

20. What is a Schottky contact?

It is a junction formed between a metal and n-type semiconductor. When the metal has a higher work function than that of n-type semiconductor then the junction formed is called Schottky diode.

21. What are advantages of Schottky diodes?

- In Schottky diode, stored charges or depletion region is negligible. So a Schottky diode has a very low capacitance.
- In Schottky diode, the depleting region is negligible. So the Schottky diode will immediately switch from ON to OFF state (fast recovery time).
- The depletion region is negligible in Schottky diode. So applying a small voltage is enough to produce large current.
- It has high efficiency.
- It operates at high frequencies.
- It produces less noise.

22. What are the applications of Schottky diode?

- Schottky diode can be used for rectification of signals of frequencies even exceeding 300 MHz.
- It is commonly used in switching device at frequencies of 20 GHz.

- It is used in radio frequency (RF) applications.
- It is widely used in power supplies.

23. What are the differences between Schottky diode and ohmic contacts?

S. No.	Schottky diode	Ohmic contact
1.	It acts as a rectifier	It acts as a resistor
2.	Very low forward resistance but very high reverse biased resistance	Resistance is same in both forward and reverse bias
3.	Work function of metal is greater than that of semiconductor $\phi_m > \phi_{semi}$	Work function of metal is smaller than that of semiconductor $\phi_m < \phi_{semi}$

24. Write an expression for the concentration of electrons in the conduction band of an intrinsic semiconductor.

The concentration of electrons in the conduction band of an intrinsic semiconductor is given by

$$n_e = 2\left(\frac{2\pi m_e^* k_B T}{h^2}\right)^{\frac{3}{2}} e^{(E_F - E_C)/k_B T}$$

Where m_e^*→ effective mass of electron, T→ absolute temperature, E_F→ Fermi energy, E_C→ Energy corresponding to the bottom of conduction band.

25. Write an expression for the concentration of holes in the valence band of an intrinsic semiconductor.

The concentration of holes in the valence band of an intrinsic semiconductor is given by

$$p_h = 2\left(\frac{2\pi m_h^* k_B T}{h^2}\right)^{\frac{3}{2}} e^{(E_V - E_F)/k_B T}$$

m_h^*→ effective mass of hole, T→ absolute temperature, E_F→ Fermi energy E_V→ Energy corresponding to the top of valence band

26. Write an expression for carrier concentration in n-type semiconductor.

The carrier concentration in n-type semiconductor is given by

$$n = (2N_d)^{\frac{1}{2}} \left(\frac{2\pi m_e^* k_B T}{h^2}\right)^{\frac{3}{4}} e^{(-\Delta E)/2k_B T}$$

Where $\Delta E \rightarrow E_C - E_d$ = Ionisation energy of the donor, $m_e^* \rightarrow$ Effective mass of an electron

$N_d \rightarrow$ Number of atoms per unit volume of the material, T → Absolute Temperature

27. Write an expression for carrier concentration in p-type semiconductor.

The carrier concentration in p-type is given by

$$p = (2N_\alpha)^{\frac{1}{2}} \left(\frac{2\pi m_h^* k_B T}{h^2}\right)^{\frac{3}{4}} e^{(-\Delta E)/2k_B T}$$

Where $\Delta E = (E_V - E_a) \rightarrow$ Ionisation of acceptor level, $N_a \rightarrow$ Number of acceptor atoms per unit volume of the material, $m_h^* \rightarrow$ Effective mass of hole, T → Absolute Temperature

28. Define Hall-effect.

When a conductor carrying a current (I) is placed in a transverse magnetic field (B), a potential difference is produced inside the conductor in a direction normal to the directions of the current and magnetic field.

29. Mention the uses of Hall Effect.

- It is used to find type of semiconductor.
- It is used to measure carrier concentration.
- It is used to find mobility of charge carrier.
- It is used to measure the magnetic flux density using a semiconductor sample known as Hall coefficient.

30. What are different types of Hall devices?

There are three types of Hall devices. They are

(a) Gauss Meter

(b) Electron Multiplier

(c) Electronic Wattmeter.

31. What is solid state drive?

It is a memory storage device which stores persistent data on solid-state flash memory. It is also called as semi-conductor storage device which has several advantages than hard disc drives.

32. What are the advantages and disadvantages of solid state drive?

The advantages of SSD are it uses less power, durable and performs quicker read and write operations etc. The disadvantages are high cost, less storage capacity and it has limitations in data recovery.

PART B & C

1. Obtain an expression for intrinsic carrier concentration in an intrinsic semiconductor.
2. Obtain an expression for the carrier concentration of electrons in an intrinsic semiconductor.
3. Derive an expression for concentration of holes in intrinsic semiconductors.
4. Deduce an expression for the energy band gap of an intrinsic semiconductor.
5. Sketch the variation of Fermi level with temperature and impurity concentration in extrinsic semiconductor.
6. What is Hall Effect? Give the theory of Hall Effect. Describe the Hall Effect experiment to determine the Hall coefficient of semiconductor. (OR)
   Describe Hall effect in p type semiconductor. (OR)
   Describe the Hall effect in n type semi conductor.
7. Describe the Principle, Construction and working of Schottky diode. What are its advantages and disadvantages?

UNIT IV OPTICAL PROPERTIES OF MATERIALS

1. **Classify the optical materials based on their interaction with visible light?**

   Generally, optical materials are classified into three types based on the nature of the propagation of light namely,
   - *Transparent*: The materials that allow light to pass through them with no to very little absorption/reflection are transparent.
   - *Translucent*: A substance is called translucent if it allows partial transmission.
   - *Opaque*: Opaque substances do not allow transmission of light. Any incident light gets reflected, absorbed or scattered.

2. **Define charge injection and recombination.**
   Charge injection: Charge injection is any process by which charges are injected into the conducting materials. Charge injection can be performed by external doping or by external biasing. Internally change injection can occur as minority charge injection wherein minority carriers flow from one internal region of the device to another.
   Charge recombination: It is a process by which electrons and holes recombine i.e.; pair annihilation. It can be radiative or non-radiative.

3. **What are various charge recombination processes?**
   Following are the three major charge recombination processes:
   (i) Radiative recombination: electron and hole recombine and release a photon.
   (ii) Schottky-Read-Hall recombination:
   (iii) Augar recombination:

4. **Explain optical gain and loss in a material.**
   When a light beam is incident on a material, the light beam may get amplified or attenuated. Amplification is caused by stimulated emission in the system as is often regarded as gain. Whereas induced absorption causes loss in the system and leads to attenuation.

5. **What are the selection rules for optical transition in quantum well?**
   When an electron from the conduction band transit to valence band it should fulfil below two conditions:
   (i) Conservation of momentum.
   (ii) Transition between states of the same quantum number in the valence band and conduction band are allowed.

6. **What is the consequence of quantum confinement on band gap in quantum well? OR What is the band gap energy during optical transition in quantum well?**
   The effective band gap of a semiconductor E_g^{eff} increases from its bulk value E_g by an addition of the electron and hole confinement energy corresponding to states with quantum number n=1 given by:

$$E_g^{eff} = E_g + \frac{h^2}{8m_e^* L^2} + \frac{h^2}{8m_h^* L^2}$$

Where, m_e^* and m_h^* are effective mass of electron and hole respectively. L is the length of the potential well and h is the Planck's constant.

7. What is solar cell and on what principle it works?

It is a *P* - *N* junction diode which converts solar energy (light energy) into electrical energy and it works on the principle of photovoltaic effect. When a pn junction is formed, an emf is generated at the depletion region.

8. What is LED? Write down the working principle of LED.

LED is light emitting diode and works under forward bias.

LED works on the principle of radiative recombination. When an electron in conduction band recombines with a hole in valence band of a direct band gap material, energy equivalent to band gap energy is emitted in the form of photon.

The forbidden gap energy is given by $E_g = h\nu$

9. Write any five advantages of LEDs?

- LEDs are smaller in size. A number of LEDs can be stacked together in a small space to form numerical display
- LED's can be turned ON and OFF in less than 1 nano second (10^{-9} second). So, they are known as fast devices.
- Variety of LEDs are available which emit light of different colours like red, green, yellow etc.
- Light modulation can be achieved with pulse supply.
- It has long life time.
- It has low drive voltage and low noise.
- It is easily interfaced to digital logic circuits.
- It can be operated over a wide range of temperatures.

10. What are the disadvantages of LEDs?

- They require high power.
- Their preparation cost is high when compared to LCD.

11. List out the applications of LEDs?

- Because of their miniature size, they are widely used in numeric and alphanumeric display devices.
- They are used as indicator lamps.
- They are used as light sources in fiber-optic communication system.

- Infrared LEDs are used in burglar alarms.
- They are used in image sensing circuits used for picture phone.

11. Justify, why LEDs are preferred to have a hemispherical shape.

LEDs are preferred to have a hemispherical shape primarily for their superior light distribution, providing uniform illumination in all directions. This shape also enhances viewing angles, reduces glare, and offers aesthetic appeal while maintaining mechanical strength and optical efficiency.

12. What is organic light emitting diode?

Organic light emitting diodes (OLEDs) are solid state devices made up of thin films of organic molecules that produce light with the application of electricity.

13. Mention few advantages of organic semiconductors over inorganic semiconductors.

They are light weight, low-cost production, low-temperature processing, mechanical flexibility, and abundant availability – that distinguish them from their conventional inorganic counterparts.

14. Specify the advantages of OLED?

- OLED's are tough enough to use in portable devices such as cellular phones, digital video cameras, DVD players, car audio equipment etc.,
- Can be viewed up to 160 degrees.
- High information applications including videos and graphics (Active matrix)
- OLEDs are paper-thin
- Upto 20% to 50% cheaper than LCD processes.
- Takes less power.

15. What are drawbacks of OLED?

- The biggest technical problem for OLEDs is the limited lifetime of the organic materials.
- The intrusion of water into displays can damage or destroy the organic materials.
- Color - The reliability of the OLED is still not upto the mark. After a month of use, the screen becomes non-uniform.

16. Mention some applications of OLED?

- OLED technology is used in commercial applications such as small screens for mobile phones and portable digital audio players (MP3 players), car radios, digital cameras and high-resolution micro displays for head-mounted displays.
- They can be used in television screens, computer displays, advertising, information and

indication.

- OLEDs can also be used in light sources for general space illumination and large-area light-emitting elements.

17. How does OLED offer advantages over LED/LCD technology?

1) OLED is very thin and more flexible

2) Light emission is brighter than normal LED

3) They have large field of view

18. What is a laser diode?

It is a specially fabricated p - n junction diode. This diode emits laser light when it is forward – biased due to stimulated emission of photon triggered by radiative recombination of electron and holes.

19. Mention some characteristics of Laser diodes?

1. It is coherent
2. It is monochromatic
3. It is collimated

20. Enumerate the benefits of Laser diodes?

- This laser is very small in size and compact
- It has high efficiency
- The laser output can be easily increased by increasing the junction current.
- It is operated with less power than ruby and CO_2 lasers.
- It requires very little additional equipment.
- It emits a continuous wave output or pulsed output.

21. Mention any four applications of Laser diodes?

- Used in fiber optic communication.
- Used in various measuring devices such as range finders, bar-code readers.
- Used in printing industry both as light sources for scanning images and for resolution printing plate manufacturing.
- Infrared and red laser diodes are common in CD players, CD-ROM and DVD technology. Violet lasers are used in HD-DVD and Blue-ray technology
- High power laser laser diode is used in industrial applications such as heat treating, cladding, seam welding and for pumping other lasers.
- Used in laser medicine especially, dentistry.

22. What is meant by electro optic effect?
The modulation of optical behavior under the influence of an electric field is called electro-optic effect. The materials which exhibit this effect are called electro-optic materials.

23. What are optoelectronic devices?
Devices that transforms electrical energy into light and light energy into electrical energy using semiconductors are optoelectronic devices. Eg,; LED, solar cells and photo diodes.

24. What are optical modulators?
A device that modulates or varies the amplitude, phase or polarization of an optical signal in a controlled manner is an optical modulator.
It generates desired intensity, colour in the passing light by changing optical parameters such as transmission factor, refractive index, reflection factor, degree of deflection and coherency of light in the optical system according to the modulating signal.

25. Classify optical modulators based on properties of the material that are used to modulate the light beam.

Based on properties of the material that are used to modulate the light beam, optical modulators can be classified as:

(i) Absorptive modulator: In absorptive modulators the absorption coefficient of the material is changed.

(ii) Refractive modulator: in refractive modulators the refractive index of the material is changed.

26. What is meant by optical switching?
Optical or photonic switching refers to a phenomenon in which transmission of an optical field through a device is switched among two or more possible states by optical means. There are two types of optical switching, linear optical switching and non linear optical switching.

PART B & C

1. Explain scattering of light in solids.

2. Describe absorption and emission of light in metal, insulator and semiconductor.

3. Describe the construction and working of photodiode.

4. Explain the construction and working of a solar cell.

5. Explain the construction and working of a LED with energy band diagram.

6. Describe the construction and working of laser diodes. What are the advantages of these diodes?
7. Explain in detail the optical processes in organic semiconductor devices. How these processes can be used to describe working of an OLED.

UNIT V MATERIALS FOR ENERGY APPLICATIONS

Part A- 2 MARKS Q & A

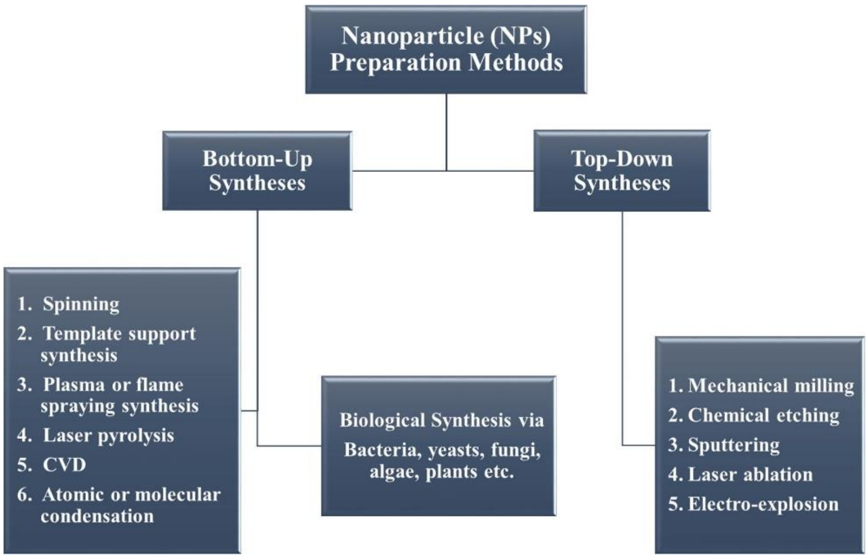
1. What are nano particles?

Nanoparticles are particles in which at least one of the dimensions is within 1 to 100 nm.

2. What are the two methods to synthesize nanomaterials?

(i) Top down: To synthesize a nanomaterial if a bulk material is used as a starting materis then this method is top down.

(ii) Bottom up: In this method atom by atom arrangement is carried out to prepare nanomaterial.



3. Write few properties of nano particles.

The properties of nano particles are,

- They have high surface to volume ratio.
- The nano materials have high strength, hardness, mobility and toughness.
- Optical properties of nanomaterials are quite different from their bulk counterpart.
- Electrical conductivity is decreased due to increased surface scattering. And it can be increased due to better ordering and ballistic transport.
- Nano particles, have lower melting temperature when compared with the bulk form.
- Due to huge surface energy, ferromagnetism in nanomaterials disappears and changes to superparamagnetism.

- Increased perfection enhances chemical stability.

4. **What are important mechanical properties of nano phase materials?**

The mechanical properties of nano phase materials are,

- They have higher moduli of elasticity.
- They have higher hardness and mechanical strength when grain size reduces from 1 μm to 10 nm.
- They have very high ductility and super plastic behavior at low temperatures (in brittle ceramics and intermetallics).
- They exhibit superelasticity.

5. **What are the magnetic properties of nanomaterials?**

The magnetic properties of nanomaterials are,
- Non-magnetic materials become magnetic when the cluster size reduces to about 80 atoms. Bulk magnetic moment increases with decrease in coordination number.
- Ferromagnetic materials exhibit super paramagnetism at nano grain sizes.
- Paramagnetic materials exhibit ferromagnetism at nano grain sizes.

6. **What is a carbon nano tube?**

Carbon nanotube (CNT) are large cylindrical molecules consisting of a hexagonal arrangement of sp^2 hybridized carbon atoms, which may be formed by rolling up single or multiple sheets of graphene.

7. **Differentiate single and multiwalled CNT.**

Single walled CNT	**Multi walled CNT**
Single layer of graphene	Multiple layer of graphene.
Catalyst is required for synthesis.	Can be produced without catalyst.
Bulk synthesis is difficult.	Bulk synthesis is easy.
Purity is poor.	Purity is high.
A chance of defect is more during functionalization.	A chance of defect is less but once occurred it’s difficult to improve.
It is easily twisted and are more pliable.	It can’t be easily twisted.

8. **Mention some properties of carbon nano tubes.**

- The properties of carbon nano tubes are,

- Carbon nano tubes are metallic or semiconducting depending on the diameter and chirality (ie., how the tubes are rolled).
- The energy gap also varies along the tube axis and reaches a minimum value at the tube ends.
- The strength of the carbon-carbon bond is very high therefore any structure based on aligned carbon-carbon bonds will ultimately have high strength.
- One of the important properties of nano tubes is their ability to withstand extreme strain.
- Nano tubes have a high strength-to-weight ratio.
- Nano tubes have a high thermal conductivity and the value increases with decrease in diameter.

9. Write down the applications of carbon nano tube.

- The applications of carbon nano tube are
- The unusual properties of carbon nano tubes have many applications such as battery electrodes, electronic devices and reinforcing fibers for stronger composites etc.,
- Carbon nano tubes can be used to make a computer switching device.
- Carbon nano tubes have many applications in battery technology. Lithium which is a charge carrier in some batteries, can be stored inside nanotube.
- Carbon nano tube can be used for storing the hydrogen which is used in the development of fuel cells.
- Nano tubes can be used to increase the tensile strength of steel.

10. What are carbon nanofibres (CNFs)?

Carbon nanofibers are cylindrical nanostructures with graphene layers arranged as stacked cones, cups or plates.

11. Mention a few applications of CNF's.

Carbon nanofibers (CNFs) are promising materials in many fields, such as photocatalytic, nanocomposites, energy devices, filtration, sensors, tissue engineering, and drug delivery.

12. Mention a few techniques to prepare CNFs.

Chemical vapor deposition, electrospinning, templating, drawing, and phase separation are the essential routes to synthesize CNFs.

13. How is CNT different from CNF.

In CNT graphene layers are wrapped as hollow cylinders whereas in CNF, the graphene layers can be stacked as platelet, ribbon like or herringbone structure.

14. What are the drawbacks of CNF's over CNTs?

CNFs have lower surface area, more defects, and larger size in comparison with CNT.

15. How is energy stored in supercapacitor cells?

Supercapacitor construction incorporates highly porous carbon materials to form electrodes that store electric charge electrostatically on its surface area. The electrode material offers a surface area of up to 3000 m^2/g, which gives supercapacitors their ultra-high capacitance.

16. What are the advantages of supercapacitor modules v/s batteries?

Supercapacitors offer higher power densities, longer lifetimes and cycle lifes, require virtually no maintenance, inherently safe operation and have wide operating temperatures. All of these features combine for lower total cost of ownership in applications requiring high power and/or short runtimes.

17. Can we pair supercapacitors with batteries?

Yes. Pairing supercapacitors with batteries to create a hybrid energy storage system (HESS) can provide an optimal energy storage solution in terms of energy density, power density and overall system lifetime that helps improve total cost of ownership. Existing applications have integrated in a passive configuration by placing the two technologies directly in parallel or in an active system which uses a multiple input Power Conditioning System (PCS).

18. How do supercapacitors work?

The working principle of supercapacitors is similar to that of standard capacitors. Basic capacitors store energy between two conducting plates or electrodes, separated by a non-conducting region or a dielectric. Supercapacitors store charges at the interface between an electrode and an electrolytic solution which creates a capacitor at each electrode. A supercapacitor essentially bridges the gap between a battery and a capacitor. Furthermore, supercapacitors exhibit much faster charging and discharging speeds than a battery while storing much more charge than an electrolytic capacitor.

19. Give a broad classification of supercapacitors.

Supercapacitors are classified into three types:

1. Electrostatic double-layer capacitors
2. Pseudo-capacitors
3. Hybrid capacitors

20. What is a fuel cell?

A fuel cell is an energy conversion device that combines fuel and air to produce electrical power directly. Fuel cells offer the promise of high efficiency and zero emissions when compared to conventional technologies. If pure hydrogen is used as a fuel, then only heat, electricity, and water are produced.

21. How is a fuel cell different than a battery?

Unlike a battery, a fuel cell does not store energy. Instead, it converts energy from one form to another (much like an engine) and will continue to operate as long as fuel is fed to it.

22. What are the benefits of fuel cells?

Fuel cells can provide clean energy and emit no pollution. Benefits of using fuel cells include:

- Safe and quiet performance.
- Higher energy efficiency than diesel or gas engines.
- Clean, zero emissions.
- High reliability and ease of operation.

PART B & C

1. Explain in detail the structure and types of Carbon Nano Tubes (CNT's) with applications.
2. What are carbon nano tubes and carbon Nano Fibers (CNF's)? Explain their significance for hydrogen storage.
3. Explain the concepts involved in the storage of electrochemical energy in super-capacitors? Mention its types and applications.
4. Discuss the Role of carbon nano-materials as electrodes in batteries and super capacitors.
5. What are the types of fuel cells? Discuss the working of fuel cells with applications.

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