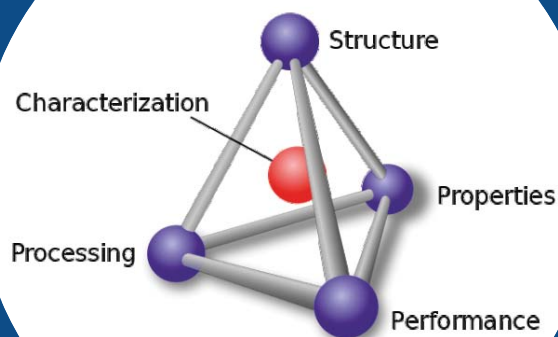




**ESE | GATE | PSUs**

# **ELECTRONICS & TELECOMMUNICATION ENGINEERING MATERIALS SCIENCE**

**Volume-I & II: Study Material with Class Room and Self Practice Questions (Workbook)**



# Materials Science

## 1. Basics of solid state physics - Crystallography

### Level-1

01. Ans: (d)

Sol: Vander walls crystal is chemically highly inactive atoms are Inert gas atoms.

02. Ans: (b)

Sol: Hexagonal crystal  $\Rightarrow a = b \neq c; \alpha = \beta = 90^\circ, \gamma = 120^\circ$

Rhombohedral crystal  $\Rightarrow a = b = c, \alpha = \beta = \gamma \neq 90^\circ$

Triclinic crystal  $\Rightarrow a \neq b \neq c; \alpha \neq \beta \neq \gamma \neq 90^\circ$

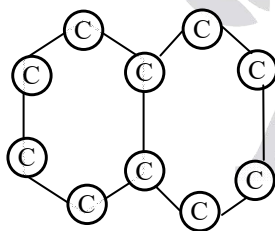
Monoclinic crystal  $\Rightarrow a \neq b \neq c; \alpha = \beta = 90^\circ \neq \gamma$

03. Ans: (c)

Sol: GaAs crystallize in Zinc Sulphide form.

04. Ans: (a)

Sol: Graphite:



1. In Graphite every carbon atom 3 valence electrons shares with 3 other carbon atoms and forms covalent bonds and the 4<sup>th</sup> valence electron is bonded with other layer of graphite with weak vander waal's bond

2. The graphite has good electrical and thermal conductor due to presence of 4<sup>th</sup> valence electron.

05. Ans: (b)

Sol: In FCC, every corner of the cubic cell and face of the cubic cell, the atoms are present and packing efficiency is 0.74. If inside of the cubic cell also atom present, then it represent BCC.

06. Ans: (c)

Sol: The intercepts of the plane are  $\frac{1}{2}, \frac{1}{2}, 1$  and its reciprocals are (2, 2, 1). Therefore, the miller indices are (221)

07. Ans: (d)

Sol: Diamond has a diamond cubic structure with atomic packing factor (or) packing density is 0.34. It is the lowest packing density material because in diamond, carbon atoms have low mass number, and hence a smaller radius. small atoms cannot be packed closely.

08. Ans: (b)

Sol: Find Reciprocals of the intercepts of the plane. Miller indices obtained after taking LCM.

**Example:** For Fig.1, intercepts are  $1, \alpha, \alpha$ . Their reciprocals are  $1, 0, 0$ . Hence Miller Indices (100). Similarly, for the other planes, (200) (100) (111)

09. Ans: (a)

Sol: FCC with two atoms basis of (0 0 0) and a  $(i + j + k)/4$ .



10. Ans: (c)

Sol: In FCC structure

$$R = \frac{a\sqrt{2}}{4} \Rightarrow a = \frac{4R}{\sqrt{2}}$$

$$\text{Volume} = a^3$$

$$a^3 = \left(\frac{4R}{\sqrt{2}}\right)^3$$

$$\Rightarrow \frac{4 \times 4 \times 4 \times R^3}{\sqrt{2} \times \sqrt{2} \times \sqrt{2}} = 16\sqrt{2} R^3$$

11. Ans: (a)

Sol: Co-ordination numbers: It is equal to the number of nearest neighbour to an atom and number of atom touching it for simple cubic co-ordination number: 6

BCC co-ordination number: 8

FCC co-ordination number : 12

12. Ans: (a)

Sol: BCC structure

$$\text{APF} = 0.68$$

$$\text{Free volume per unit cell: } 4R = \sqrt{3} a$$

$$a = \frac{4R}{\sqrt{3}} = 0.2886 \text{ nm}$$

$$= a^3 \times (1 - \text{APF})$$

$$= (0.2886)^3 \times (1 - 0.68)$$

$$= 7.69 \times 10^{-3} \text{ nm}$$

13. Ans: (d)

14. Ans: (d)

Sol: The cubic cell, a line is projected from origin taken at one of the cube corner point

$$\left(\frac{1}{2}, 1, 0\right)$$

The miller direction is [1 2 0]

15. Ans: (a)

Sol: a, b, c a set of parallel planes

Intercepts are 3a, 4b

Z axis parallel to X, Y  $\therefore Z = 0$

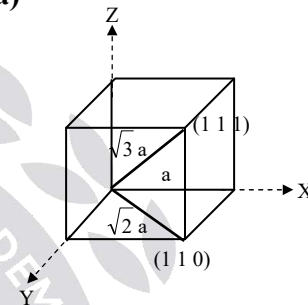
$$\begin{aligned} \text{Reciprocal} &= \frac{1}{3}, \frac{1}{4}, 0 \\ &= (4, 3, 0) \end{aligned}$$

16. Ans: (a)

Sol: Metallic iron changes from BCC to FCC at 910°C with increases in the atomic radius of iron. Then volume decreases or density increases.

17. Ans: (a)

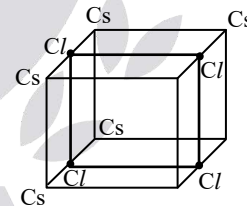
Sol:



$$\text{The simple cubic crystal is} = \frac{\sqrt{2} a}{\sqrt{3} a} = \sqrt{\frac{2}{3}}$$

18. Ans: (c)

Sol: CsCl structure



$$\text{CsCl unit cell is } \left(\frac{1}{2}, \frac{1}{2}, \frac{1}{2}\right)$$

19. Ans: (b)

Sol: x  $\rightarrow$  a = 1

y  $\rightarrow$  b = 2

z = c =  $\infty$

$$\begin{aligned} \text{intersect the cubic crystal is } &\frac{1}{1}, \frac{1}{2}, \frac{1}{\infty} \\ &= (2, 1, 0) \end{aligned}$$



20. Ans: (c)

Sol: The NET number of sodium cations per unit cell is FOUR, and the NET number of chloride anions per unit cell is also FOUR, so Z (the multiple of the simplest/empirical formula present in the cell) is 4. The 4 : 4 or 1 : 1 ratio of Na : Cl ions present in the unit cell is responsible for the chemical formula of NaCl. Recognize that no independent NaCl entity is present in the unit cell.

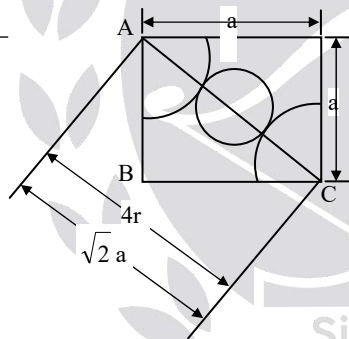
**Level-2**

01. Ans: (b)

Sol: Atomic packing fraction in FCC

$$P.F = \frac{\text{total volume of atoms in a unit cell}}{\text{volume of unit cell}}$$

$$P.F = \frac{n \cdot \frac{4}{3} \pi r^3}{a^3}$$



$$\text{FCC: } n = 4 \text{ and } a = \frac{4r}{\sqrt{2}}$$

( $\because$  considering the  $\Delta ABC$ )

$$p.f = \frac{4 \cdot \frac{4}{3} \pi r^3}{\left(\frac{4r}{\sqrt{2}}\right)^3} = 0.74$$

02. Ans: (c)

Sol: Crystal System: Orthorhombic

Lattice parameters:  $a \neq b \neq c$ ,

$$\alpha = \beta = \gamma = 90^\circ$$

Possible Bravais lattices : P, I, C, F

Examples :  $\text{KNO}_3$ ,  $\text{BaSO}_4$ ,  $\text{PbCO}_3$

03. Ans: (d)

Sol: Pure ionic solids are excellent insulators at low temperatures due to lack of free electrons; but, as 'T' increases, their ionic conductivity increases.

04. Ans: (b)

Sol: 'Cu' crystallizes in FCC structure.

05. Ans: (d)

Sol: GaAs crystallize in Zinc Sulphide form.

06. Ans: (b)

Sol: Volume of unit cell =  $a^3$ ; No. of atoms per unit cell = 2

$$\text{Radius of atom} = \frac{a\sqrt{3}}{4}$$

Packing fraction = Volume occupied by atoms / volume of the unit cell

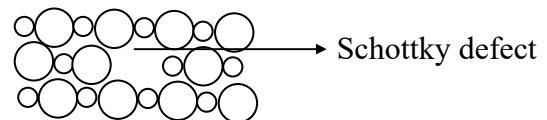
$$= \frac{2 \times \frac{4}{3} \pi \left(\frac{a\sqrt{3}}{4}\right)^3}{a^3} = \frac{\sqrt{3} \pi}{8}$$

07. Ans: (c)

Sol: Ionic Bond: Losing or gaining of electrons  
Covalent Bond: Sharing of electrons

08. Ans: (b)

Sol: Schottky defects: These defects are formed by mixing of cation and anion from the Lattice structure.



09. Ans: (c)

Sol: Whenever X-rays are reflected by a set of parallel planes X-ray diffraction spectrum is produced. Which consists of series of maxima and minima intensity. The crystals are having the structured parallel plane. Hence crystal exhibits uniform X-ray diffraction pattern.



10. **Ans: (a)**

**Sol:** Both Assertion and Reason are true and Reason is the correct explanation of Assertion.

11. **Ans: (b)**

**Sol: Reason:** The no. of atoms per unit cell in BCC Crystal = 2

The number of atoms per unit cell in FCC crystal = 4. So, the difference is  $4 - 2 = 2$

12. **Ans: (c)**

**Sol:** The presence of dislocations makes a crystal mechanically weak. Because of the easy movement of dislocations. The strength of material can be increased by removing all dislocations and making the material a perfect crystal. This is difficult to achieve except in very small hair like crystals (whiskers).

13. **Ans: (c)**

**Sol:** In Bravais lattices we have one hexagonal primitive lattices.

14. **Ans: (c)**

**Sol:** NaCl unit cell contains  $4 \text{ Na}^+$ ,  $4 \text{ Cl}^-$  ions.

15. **Ans: (a)**

**Sol:** Number of atoms of A from corners of unit cell =  $8/8 = 1$ .

Number of atoms of B from corners of unit cell =  $8/8 = 1$ .

$A : B = 1 : 1 \Rightarrow \text{A}_1\text{B}_1$

16. **Ans: (d)**

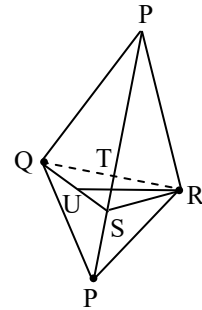
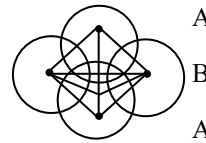
**Sol:** These are only fourteen independent ways of arrangement points in a three dimensional space lattice is said to be a bravais lattice. These 14 bravais lattice belong to seven crystal and seven multiple crystal system.

17. **Ans: (d)**

**Sol:** For ideal hexagonal crystal structure is

$$\frac{c}{a} = 1.633$$

(or)



In HCP arrangement the layers are stacked in ABA as shown in figure. The point Q, R and S represent the centers of atoms on plane B and P is the centre of atoms in plan A just above and below the plane B. Joining the points Q, R & S to P results in two tetrahedral with common base.

$$a = QR = RS = SQ \text{ \& } c = 2PT$$

$$\frac{c}{a} = \frac{2PT}{RS}$$

$$RU = \sqrt{RS^2 - SU^2} = \sqrt{a^2 - \frac{a^2}{4}}$$

$$RT = \frac{2}{3}RU = \frac{2}{3}\sqrt{3} \cdot \frac{9}{2} = \frac{9}{\sqrt{3}}$$

$$PT = \sqrt{PR^2 - RT^2} = \sqrt{a^2 - \frac{a^2}{3}} = \frac{a\sqrt{3}}{\sqrt{3}}$$

$$\frac{c}{a} = \frac{2 \cdot PT}{RS}$$

$$= \frac{2 \cdot a\sqrt{3}}{a}$$

$$\frac{c}{a} = \frac{2\sqrt{3}}{1} \Rightarrow \frac{c}{a} = 1.633$$

18. **Ans: (a)**

**Sol:** Zinc sulphide (ZnS) is the prototype II-VI semiconductor.

Its cubic form ( $\beta$  - ZnS), which occurs naturally as a mineral has given the name zincblende to the crystal structure also called sphalerite.





19. **Ans: (c)**

**Sol:** A metallic bond results from the electrostatic attraction between the negative free electron gas and positive ion cores.

20. **Ans: (c)**

**Sol:** Thermal conductivity of material is dependent molecular vibrations. In case of non metals there are no free electrons so, only the molecular vibration are responsible for conduction of heat and hence for non metals the conductivity increase with increase in temperature.

21. **Ans: (b)**

**Sol:** The defects occurs due the requirement of thermodynamic equilibrium vacancies.

22. **Ans: (b)**

**Sol:** MgO → ionic bonding  
SiC → covalent bonding  
Solid NH<sub>3</sub> → Hydrogen bonding  
Solic CH<sub>4</sub> → Vander waals bonding.

23. **Ans: (b)**

**Sol:** Given data spacing (1, 1, 1)

$$\text{Inter planner distance } \lambda = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

$$\frac{a}{\sqrt{1^2 + 1^2 + 1^2}} = \frac{a}{\sqrt{3}}$$

$$4R = \sqrt{2} a$$

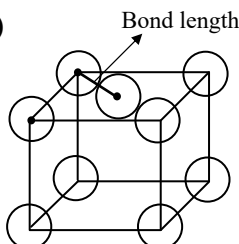
$$a = \frac{4R}{\sqrt{2}} \Rightarrow 0.362$$

$$\lambda = \frac{0.362}{\sqrt{3}}$$

$$= 0.209 \text{ nm} = 2\text{Å} \quad (\text{Note: } 1\text{Å} = 0.1 \text{ nm})$$

24. **Ans: (a)**

**Sol:**



$$\text{FCC lattice is } 4r = \sqrt{2} a$$

$$2(2r) = \sqrt{2} a$$

$$2(D) = \sqrt{2} a$$

$$D = \frac{\sqrt{2} a}{2} \Rightarrow D = \frac{a}{\sqrt{2}}$$

25. **Ans: (d)**

**Sol:** H<sub>2</sub>O is a covalent bond/ hydrogen bond.

26. **Ans: (b)**

**Sol:** Sodium chloride (NaCl) has a cubic unit cell, it is best thought of as a face-centred cubic (FCC) array of an ions with an inter penetrating FCC cation lattice (or) vice-versa.

27. **Ans: (d)**

**Sol:** The unit cell of zinc blende structure has a four zinc ions and four sulphur ions.

28. **Ans: (a)**

**Sol:** Ionic solids are soluble in polar solvents like water and liquid ammonia.

Ionic solids have high melting and boiling points, pure and dry ionic solids are good insulators because all the electrons are tightly bound.

29. **Ans: (d)**

**Sol:** The infrared spectrum of the 1:1 complex in the vapour phase between water and hydrogen fluoride (HF) has been observed for the first time.

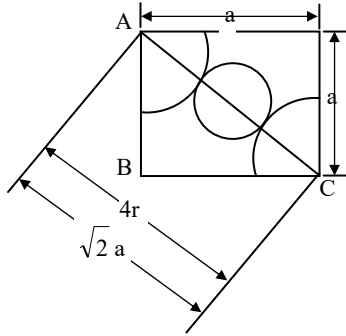
30. **Ans: (c)**

31. **Ans: (a)**

**Sol:** Atomic packing fraction in FCC

$$P.F = \frac{\text{total volume of atoms in a unit cell}}{\text{volume of unit cell}}$$

$$P.F = \frac{n \cdot \frac{4}{3} \pi r^3}{a^3}$$



$$\text{FCC: } n = 4 \text{ and } a = \frac{4r}{\sqrt{2}}$$

( $\because$  considering the  $\Delta ABC$ )

$$\text{p.f} = \frac{4 \cdot \frac{4}{3} \pi r^3}{\left(\frac{4r}{\sqrt{2}}\right)^3} = 0.74$$

**32. Ans: (d)**

**Sol:** Metals do not have the property of transparent to electromagnetic radiation.

**33. Ans: (c)**

**Sol:** Copper, silver and gold the covalent bond which are filled in the ground state are treated in E-B model as transition elements in order to account for their bond strengths and FCC lattices. A larger position of bonding is attributed to their d states. These considered to have  $d^{9.3} SP^{0.7}$  electron configuration with 2.4 bonding electrons per ion.

**34. Ans: (b)**

**Sol:** Covalent substances are soluble in some non polar solvents like benzene and carbon disulphide. The melting and boiling points of covalent solids are usually low as compared to those of ionic compounds. Some covalent solids are Conductors (lead, tin) some are semiconductors (Si, Ge) and some are insulators (Carbon in diamond form). Covalent compounds can exist as solids, liquids and gases.

**35. Ans: (a)**

**Sol:** Number of atoms per unit cell in diamond structure = 8.

**36. Ans: (b)**

**Sol:** The amorphous substances posses is

1. No specific arrangement of atoms.
2. May have short range order.
3. Bond length & strength are unequal.

**37. Ans: (b)**

**Sol:** Copper crystal belongs to a closed packed FCC structure.

**38. Ans: (d)**

**Sol:** Calcium carbonate particle has a rhombohedral basic structure-even with every fine grinding rupture occurs in the grating palne (or) axis of symmetry of the natural crystal structure.

**39. Ans: (c)**

**Sol:** Cesium chloride, is the inorganic compound with the formula CsCl. This colorless solid is an important source of cesium ions in a variety of niche applications. Its crystal structure forms a major structural type where each cesium ion is coordinated by 8 chlorine ions.

## 2. Conducting materials

### Level-1

**01. Ans: (b)**

**Sol:** Any impurities will act as scattering centers and resistivity increases (or) conductivity decreases.

**02. Ans: (c)**

**Sol:** Hall voltage  $V_H = ?$

Thin copper plates  $t = 0.1 \times 10^{-3} \text{ m}$

$B_2 = 1 \text{ Wb/m}^2$

$R_H = 7.4 \times 10^{-11} \text{ m}^3/\text{c}$



$$I = 100 \text{ A}$$

$$V_H t = B_Z R_H I$$

$$V_H t = B_Z R_H I$$

$$V_H = \frac{B_Z R_H I}{t}$$

$$V_H = \frac{1 \times 7.4 \times 10^{-11} \times 100}{0.1 \times 10^{-3}}$$

$$V_H = 7.4 \times 10^{-5}$$

$$= 74 \times 10^{-6} = 74 \mu\text{V}$$

(or)

$$R_H B I$$

$$V_H = \frac{R_H B I}{t}$$

$$\text{Hall voltage } V_H = 74 \mu\text{V}$$

**03. Ans: (a)**

**Sol:** The electrical conductivity of solid solution is lesser  $10^{14}$  Hz the pure metals. It decreases with increase in alloy content because of creating crystallographic imperfection by adding alloying elements and due to that regular structure is disturbed so statement I and statement II are correct and statement II is correct explanation for statement –I.

**04. Ans: (a)**

**Sol:** In hard drawn copper, cold working will increase mechanical distortions (dislocations) which act as electron scattering centers and resistivity will be more. In annealing, lattice defects get reduced and resistivity will be less.

**05. Ans: (b)**

**Sol:** Both the sentences are individually correct but statement (II) is not correct explanation for statement (I).

**06. Ans: (a)**

**Sol:** Carbon (Diamond) → Insulation

Silicon → Semiconductor

Tin & Lead → Conductor

**07. Ans: (a)**

**Sol:** According to classical free electron theory, the electrons in a metal are subjected constant potential.

**08. Ans: (b)**

**Sol:** Lead is a good conducting, low strength material. It possess good malleability and ductile properties. It is least affected by sea water.

If forms alloy with many other metals (Ex:- soldering alloy of pb + sn) and it is also used in cable sheath

**09. Ans: (a)**

**Sol:** The electrical resistivity of silver is lower than that copper. So the statement II is incorrect.

The electrical conductivity of metal decreases by adding impurities to the host material, even though by adding high conductivity (silver) atoms added to copper as an impurity, it's overall conductivity decreases then pure host material

**10. Ans: (a)**

**Sol:** A good conductor of electricity is as follows:

1. It's conductivity decreases with increasing temperature

$$\rho_2 = \rho_1 [1 + \alpha(T_2 - T_1)]$$

2. Number of free electrons is around  $10^{28}$  per  $\text{m}^3$

3. It's conductivity decreases with addition of impurities

4. There also possess good thermal conductivity





**11. Ans: (c)**

**Sol:** If the temperature of metal increases, the lattice vibration in the crystal structure increases. Hence collision frequency increases and relaxation time decreases. Due to that resistivity of metal increases

**12. Ans: (a)**

**Sol:** Given data,  
Temperature co-efficient of resistance of a wire =  $0.0008/^\circ\text{C}$   
The resistance of the wire =  $8\Omega$  at  $0^\circ\text{C}$   
Then  $100^\circ\text{C}$   
 $r = ?$   
 $\rho(100) = \rho(0) [1 + 0.0008 \times 100]$   
 $= 8.64 \text{ Ohm}$

**13. Ans: (b)**

**Sol:** Because increasing the impurity content destroys the periodicity of the lattice, which decreases the conductivity.

**14. Ans: (b)**

**Sol:** According to Weidemann – Franz law  
 $\frac{k}{\sigma} \propto T$  ;  $\frac{k}{\sigma} = LT$  ,  
where L- Lorentz number.

**15. Ans: (a)**

**Sol:** We have  $V_d = \mu E$  and  $\mu = \frac{Q_e E T}{m_e}$

**16. Ans: (a)**

**Sol:** In a Hall effect except the applied magnetic field is doubled while the ohmic current density is left unchanged. As a result, the Hall voltage is doubles.

**17. Ans: (a)**

**Sol:** Given data,  
 $n_i = 2.37 \times 10^{19} \text{ m}^3$   
 $\mu_e = 0.38 \text{ m}^2\text{V}^{-1}\text{S}^{-1}$   
 $\mu_n = 0.18 \text{ m}^2\text{V}^{-1}\text{S}^{-1}$   
Conductivity  $\sigma = n_i e (\mu_e + \mu_n)$

$$= 2.37 \times 10^{19} \times 1.6 \times 10^{-19} (0.38 + 0.18)$$

$$= 2.1235 \Omega^{-1}\text{m}^{-1}$$

**18. Ans: (d)**

**Sol:** Hall effect:

- (i) Sign and concentration of carriers
- (ii) Mobility and drift velocity of carriers.
- (iii) Conductivity and type of semi conductors.

**19. Ans: (d)**

**Sol:** When a n-type semiconductor sample is used in this experiment, both electron and holes get deflected towards the upper surface of the block. But as the electron concentration is more than that of holes, the potential of the upper surface is negative with respect to the lower surface. And the Hall potential difference is negative. Thus the Hall coefficient  $R_H$  is negative for n-type semiconductors.

**20. Ans: (c)**

**Sol:** When no current is passed through a conductor, the average velocity of a free electron over a large period of a time is zero. The average of the velocities of the free electrons at an instant is zero.

**Level-2**

**01. Ans: (a)**

**Sol:** An electrical balanced atom has to protons and 2 electrons in the outermost shell. An insulator material made of such atom with  $Z = z_0$  is zinc.

**02. Ans: (a)**

**Sol:** Manganin alloy has the lowest temperature coefficient of resistance:  $0.0000002 \Omega / ^\circ\text{C}$ .



**03. Ans: (d)**

**Sol:**

Model	Particle properties	Examples
1. Maxwell-Boltzmann	Distinguishable unlimited particles per quantum state	Ideal gas, Molecules
2. Bose Einstein	Indistinguishable unlimited particles per quantum state	Photon, phonon
3. Fermi Dirac	Indistinguishable, identical one particle  Per quantum state (Pauli exclusion principle)	Electron, protons

**04. Ans: (c)**

**Sol:** The Fermi energy is defined as the energy of the top most filled level in the ground state of the N electron system Fermi energy

$$(E_F) = \frac{h^2}{2m} \left( \frac{3\pi^2 N}{L^3} \right)^{2/3}$$

$$E_F \propto N^{2/3}$$

**05. Ans: (c)**

**Sol:** Group III elements (trivalent impurity) when added to an element semiconductor results in formation of p-type semiconductor.

Group III elements: Boron, Aluminium, Gallium, and Indium

**06. Ans: (c)**

**Sol** The resistivity of a metal is a function of temperature because with increasing temperature, the lattice vibrations increases and due to that collision of electrons takes place.

**07. Ans: (b)**

**Sol:** Based on kinetic theory of gases, the electron have constant velocity, and velocity of electrons is

$$V_{rms} = \sqrt{\frac{3k_p T}{m}}$$

**08. Ans: (c)**

**Sol:** Germanium is a semi conductor

**09. Ans: (d)**

**Sol:** Manganin has almost zero temperature variation of resistance.

**10. Ans: (b)**

**Sol:** According to Matthiessen's rule  $\rho = \rho_r + \rho_T$ ;  $\rho_r$  depends on the structural defects of the material and imperfections.  $\rho_T$  is temperature dependent.

**11. Ans: (a)**

**Sol:** Given data,

A conductor carrier a current = 4 A

$$e = 1.6 \times 10^{19}$$

B = ?

$$I^p = \frac{q}{t} = \frac{n e}{t}$$

$$\text{Therefore, } n = \frac{I^p \times t}{e} = 2.5 \times 10^{19}$$

**12. Ans: (d)**

**Sol:** Addition of any impurity increases the resistivity of host material

**13. Ans: (c)**

**Sol:** 1 Aluminium is used in Telephone cords and trolley wires.

2. Phosphor Bronze is used in current carrying springs

3. Carbon is used in commutator brush

4. Nichrome is used in heating elements

**14. Ans: (c)**

**Sol:** Because impurity atoms act as scattering centers this increases the resistivity.



**15. Ans: (a)**

**Sol:** Two samples of Ge and silver are heated from 0 K to 300 K. Then the conductivity of Ge increases and silver decreases.

**16. Ans: (c)**

**Sol:** Energy bands occur in solids where the discrete energy levels of the individual atoms merge into bands which contain a large number of closely spaced energy levels. In this section, we first discuss the crystal structure of common semiconductors to illustrate the fact that most semiconductors have an ordered structure in which atoms are placed in a periodic lattice. We then consider the Kronig-Penney model. This one dimensional model illustrates how a periodic potential yields a set of energy bands and energy band gaps.

**17. Ans: (b)**

**Sol:** A metal consists of electrons which are free to move about in the crystal like molecules of a gas in a container. Mutual repulsion between electrons is ignored and hence potential energy is taken as zero.

**18. Ans: (c)**

**Sol:** Fermi energy of metal ( $E_F$ ) = 1.4 eV  
 $K = 1.38 \times 10^{-23} \text{ J/K}$   
 $e = 1.6 \times 10^{-19}$

$$\text{Fermi temperature } (T_F) = \frac{E_F}{k}$$

$$T_F = \frac{1.4 \times 1.6 \times 10^{-19}}{1.38 \times 10^{-23}} = 1.6 \times 10^4 \text{ K}$$

**19. Ans: (b)**

**Sol:** Given data,  
 $n = 6 \times 10^{28}$ ,  $e = 1.6 \times 10^{-19}$ ,  $\tau = 1.4 \times 10^{-14}$

$$\begin{aligned} \text{conductivity } \sigma &= \frac{ne^2\tau}{m} \\ &= \frac{6 \times 10^{28} \times (1.6 \times 10^{-19})^2 \times 1.4 \times 10^{-14}}{9.1 \times 10^{-31}} \\ &= 2.36 \times 10^7 \end{aligned}$$

**20. Ans: (c)**

**Sol:** Given data,  
 $n = 5.8 \times 10^{28}$ ,  $e = 1.6 \times 10^{-19}$ ,  $m = 9.1 \times 10^{-31}$

$$\rho = 1.54 \times 10^{-8}$$

$$\rho = \frac{ne^2\tau}{m}$$

$$\frac{1}{\rho} = \frac{ne^2\tau}{m}$$

$$\begin{aligned} \tau &= \frac{m}{\rho ne^2} = \frac{9.1 \times 10^{-31}}{1.54 \times 10^{-8} \times 5.8 \times 10^{28} \times (1.6 \times 10^{-19})^2} \\ &= 3.979 \times 10^{-14} \text{ s} \end{aligned}$$

**21. Ans: (b)**

**Sol:** Given data,

$$R_H = 3.66 \times 10^{-4}$$

$$e = 9 \times 10^3$$

$$n_h = \frac{1}{R_H e}$$

$$n_h = \frac{1}{3.66 \times 10^{-4} \times 1.6 \times 10^{-19}}$$

$$n_h = 1.7076 \times 10^{22}$$

$$\text{Mobility of carries } \mu_n = \frac{1}{\rho ne}$$

$$\begin{aligned} &= \frac{1}{9 \times 10^{-3} \times 1.707 \times 10^{22} \times 1.6 \times 10^{-19}} \\ &= 0.41 \text{ m}^2/\text{V-s} \end{aligned}$$

**22. Ans: (a)**

**Sol:** Given data,

Length = 10 mm, breadth = 10 mm,

Thickness = 1 mm,

$$R_H = 3.66 \times 10^{-4}$$

$$B = 0.5 \text{ Wb/m}^2$$

$$\text{Hall voltage } V_H = \frac{BIR_H}{W}$$

$$= \frac{0.5 \times 10^{-2} \times 3.66 \times 10^{-4}}{10 \times 10^{-3}}$$

$$= 18 \text{ mV}$$



**23. Ans: (b)**

**Sol:** The Fermi energy is defined as the energy of the top most filled level in the ground state of the N electron system Fermi energy

$$(E_F) = \frac{h^2}{2m} \left( \frac{3\pi^2 N}{L^3} \right)^{2/3}$$

$$E_F \propto N^{2/3}$$

$$N \propto E_F^{3/2}$$

**24. Ans: (c)**

**Sol:** As the temperature of a metallic resistor is increased, the product of its resistivity and conductivity is increases.

**25. Ans: (a)**

**Sol:** A resistor of resistance R is connected to an ideal battery. If the value of R is decreased, the power dissipated in the resistor will increase.

**26. Ans: (d)**

**Sol:** When a resistor connected to a battery is heated due to the current do not change in number of free electrons.

### 3. Magnetic materials

#### Level-1

**01. Ans: (a)**

**Sol:** A special class of ferrites called 'ferrox cubes' are used as computer memory elements.

**02. Ans: (a)**

**Sol:**

- Hysteresis is characteristic property of ferromagnetic materials.
- Field applied in order to destroy remenant magnetization is called coercive field.

**03. Ans: (c)**

**Sol:** A ferromagnetism property of a group of atoms or molecules in a solid crystal (or) lattice. All ferromagnetic substances have unpaired electron spins that are strongly entwined by a quantum mechanical force exchange interaction large groups of atoms in ferromagnetic substance form magnetic domains in which electron spins become locked together in alignment.

**04. Ans: (c)**

**Sol:** Hard magnetic materials are used for making permanent magnets because they have wide and large hysteresis loop, high retentivity and coercivity

**05. Ans: (d)**

**Sol:** According to curie law,

$$\chi \propto \frac{1}{T} \Rightarrow \chi = \frac{C}{T} \quad \text{Where, C: curie constant}$$

**06. Ans: (b)**

**Sol:** Given data,

A bar magnetic made of steel has magnetic moment  $2.5 \text{ Am}^2$

$$\text{Mass} = 6.6 \times 10^3 \text{ kg,}$$

$$\text{Density} = 7.9 \times 10^3,$$

$$\text{Intensity of magnetization} = ?$$

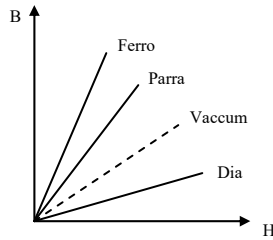
The volume of the bar magnet is

$$V = \frac{6.6 \times 10^3 \text{ kg}}{7.9 \times 10^3 \text{ kg/m}^3} = 8.3 \times 10^{-7} \text{ m}^3$$

$$\therefore I = \frac{m}{V} = \frac{2.5 \text{ A-m}^2}{8.3 \times 10^{-7} \text{ m}^3} = 3 \times 10^6 \text{ A/m}$$

**07. Ans: (c)**

**Sol:** The graph between magnetic flux density (B) and applied field (H) for different magnetic material is



**08. Ans: (c)**

**Sol:** Based on weiss- Domain Theory, the magnetic

1. Expand at initial field. If is a reversible process
2. Rotate the dipoles in domains in the direction of fields high magnetic field. It is an irreversible process.

**09. Ans: (a)**

**Sol:** Ferrites are useful at very high frequencies because of high permeability & low eddy current losses (or) high resistivity.

**10. Ans: (d)**

**Sol:** 1.No eddy current losses  $\Rightarrow$  Ferrimagnetic materials  
2. Small hysteresis losses  $\Rightarrow$  Soft magnetic materials  
3. Large hysteresis losses  $\Rightarrow$  Hard magnetic materials

**11. Ans: (d)**

**Sol:** Permalloy is an example of soft magnetic material.

**12. Ans: (b)**

**Sol:** Metallic copper is an example of diamagnetic material.

**13. Ans: (d)**

**Sol:** The spontaneous magnetization of a domain in a ferromagnetic crystal is accompanied

by an elongation or contraction in the direction of magnetization, called magnetostriction.

**14. Ans: (b)**

**Sol:** In Anti-ferromagnetic materials, above a specific Neel temperature the anti parallel arrangement breaks down and the material becomes paramagnetic, temperature dependence of susceptibility, i.e. when

$$T > T_N \text{ (Neel Temperature)} \quad \chi = \frac{C}{T + \theta}$$

**15. Ans: (d)**

**Sol:** Ferrites are metallic oxide ceramic materials insulating in nature so that ferrites are much more resistivity than ferromagnetic materials. Electrons in ferrites makes ionic bonds by complete transfer of electrons

**16. Ans: (d)**

**Sol:** Superconductors are perfect diamagnetic materials having susceptibility as  $-1$ .  
Diamagnetic material susceptibility is negative and small.  
Paramagnetic material susceptibility is positive and small.  
Ferromagnetic material susceptibility is positive and large.

**17. Ans: (a)**

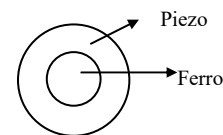
**Sol:** 1.Ferroelectric material

Eg: BaTiO<sub>3</sub>, Pb [ZrO<sub>3</sub>, TiO<sub>3</sub>], KH<sub>2</sub>PO<sub>4</sub>

2. Piezoelectric material

Eg: Quartz, BaTiO<sub>3</sub>

Pb [ZrO<sub>3</sub>, TiO<sub>3</sub>], KH<sub>2</sub>PO<sub>4</sub>



3. Soft magnetic material





Eg: Perm alloy, superm alloy, pure Iron,  
Fe-Si alloy

4. Hard magnetic material

Eg: Alnico, Tungsten Steel

**18. Ans: (b)**

**Sol:** Sodium is paramagnetic because of unpaired electrons in the outermost orbit.

**19. Ans: (d)**

**Sol:** 3d electron spin direction is responsible for magnetic moment. For Cobalt, number of 3d electrons = 7 Spin direction:  $\uparrow \uparrow \uparrow \uparrow \uparrow \downarrow \downarrow$   
 $\therefore$  Magnetic moment = 3 Bohr magnetron.

**20. Ans: (a)**

**Sol:** In a transformer, the core should have low coercivity and retentivity. Because high hysteresis loop area implies high hysteresis loss. Hence soft magnetic materials are used in the transformer core. In a transformer, the core should have high permeability to produce high magnetic flux density.

**Level-2**

**01. Ans: (c)**

**Sol:** In permanent magnets every atom behaves like a small dipole (atomic dipoles) and they are all aligned perfectly parallel to each other when heated, temperature increases, thermal agitation increases means atoms (dipolar) are vibrating at high temperatures, due to increased thermal agitation, the dipoles start realigning from their parallel orientation. All these factors causes loss of magnetism.

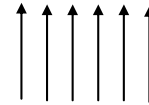
**02. Ans: (b)**

**Sol:** The magnetic field required to destroy residual magnetization is called coercivity field  $H_c$ .

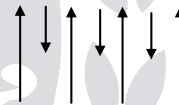
**03. Ans: (b)**

**Sol:**

- (i) Both Ferro and Ferri, have domain structures
- (ii) In both Ferro & Ferri, domain grow in size
- (iii) Ferro domains all dipoles are parallel



In Ferri, the dipoles are anti parallel and are of un-equal magnitudes. But still in 'ferri material' positive net magnetic moment can be said to be higher than Ferro, because the effective dipole moment in anti parallel arrangement is greater in magnitude. Thus Ferri materials have very high permeability and susceptibilities as compared to Ferro.



**04. Ans: (b)**

**Sol: Ideal Core Material**

- (i) for an ideal core  $\mu_r = \infty$  i.e., very high permeability and coercivity  $H_c = 0$ . such that no hysteresis loss. i.e., its B-H loop should be y-axis.  
 $\Rightarrow$  Even when there is no current, it can have any B (flux) value.
- (ii) Core saturation implies, flux in the core doesn't increase with increasing H which is undesirable.

**05. Ans: (a)**

**Sol:**  $\mu_r = 1 + \psi_m$

Where  $\psi_m$  is the magnetization susceptibility is given by

$$\psi_m = \frac{M}{H} \quad (\text{or}) \quad M = \psi_m H$$

M = Magnetization

(or)



The relative permeability of a medium  $\mu_r$  the 3 field vectors are related as

$$B = \mu_0 (M+H); \text{ as } B = \mu H$$

$$\mu H = \mu_0 (M+H)$$

$$\frac{\mu}{\mu_0} = \frac{M}{H} + 1$$

$$\mu_r = \frac{M}{H} + 1$$

**06. Ans: (c)**

**Sol:** The imaginary part of the complex dielectric constant is a measure of dielectric loss.

**07. Ans: (a)**

**Sol:** Ferrites have high resistivity and hence low eddy current loss and high Q-factor, therefore they are suitable for high frequency applications.

**08. Ans: (c)**

**Sol:** Diamagnetic materials has a highest reluctance.

**09. Ans: (d)**

**Sol:** The plays an important role in the fine recording of audio signals on speed of the motor in magnetic tape recorder.

**10. Ans: (a)**

**Sol:** Soft magnetic materials have small retentivity and coercivity. Hence can be magnetized or demagnetized easily in either direction.

**11. Ans: (a)**

**Sol:**  $B = \mu H$

$$= \mu_0 \mu_r H$$

$$\text{i. e. } B = \mu_0 \mu_r H + \mu_0 H - \mu_0 H$$

$$= \mu_0 H + \mu_0 H (\mu_r - 1)$$

$$= \mu_0 H + \mu_0 M$$

Where the magnetisation M is equal to H

$$(\mu_r - 1)$$

$$\text{i.e. } B = \mu_0 (H + M) \text{ -----(1)}$$

The first term on the right side of Eq. (1) is due to external field. The second term is due to the magnetisation.

Thus the magnetic induction (B) in a solid is

$$B = \mu_0 (H + M)$$

$$\text{Hence } \mu_0 = \frac{B}{H + M}$$

The relative permeability

$$\mu_r = \frac{\mu}{\mu_0} = \frac{B/H}{B/H + M} = \frac{H + M}{H} = 1 + \frac{M}{H}$$

$$\mu_r = 1 + \chi$$

**12. Ans: (c)**

**Sol:** Soft iron is characterized by the saturation magnetization  $M_s$  is large, coercivity  $H_c$  and retentivity  $B_c$  are small.

**13. Ans: (a)**

**Sol:** Diamagnetic susceptibility is very small and negative.

**14. Ans: (b)**

**Sol:** It is the ability of material that can change physical dimension by applying magnetic field.

**15. Ans: (c)**

**Sol:** Superconductors when cooled below their critical temperature exhibit zero resistivity.

**16. Ans: (c)**

**Sol:** Hard magnetic materials are used for making permanent magnets because they have wide and large hysteresis loop, high retentivity and coercivity.

**17. Ans: (b)**

**Sol:** The magnetic moments of diamagnetic materials are mainly due to the orbital angular momentum of the electrons. so statement I is correct.



A steady current flowing in the orbit produces a Magnetic field equivalent to that set up by a dipole perpendicular to the plane of orbit this statement is also correct but not the correct explanation for statement I.

18. **Ans: (a)**

**Sol:** Soft magnetic materials are not used in the constructions of permanent magnets, but hard magnetic materials are used. so statement I is correct.

Soft magnetic materials have narrow hysteresis loop, low retentivity and low coercivity and hence these are not used in permanent magnets.

19. **Ans: (b)**

**Sol:** If the magnetic susceptibility of a specimen is small and positive, the specimen is a paramagnetic material.

20. **Ans: (b)**

**Sol:** Structural formula for ferrite is  $\text{MgFe}_2\text{O}_3$

21. **Ans: (c)**

**Sol: Magnetostriction:** It is the ability of material that can change physical dimension by applying magnetic field.

22. **Ans: (c)**

**Sol:** The atomic thermal motions are not affecting the atomic dipole alignment.

23. **Ans: (d)**

**Sol:** Silicon element is added to iron or steel to reduce the hysteresis losses.

24. **Ans: (c)**

**Sol:** High frequency transformer cores are generally made from ferrites. These ferrites are ceramics with electrically insulating character and their eddy current losses are very low.

25. **Ans: (b)**

**Sol:** Alnico is an alloy of Al-Ni-co. It is a hard magnetic material and the hysteresis loop area is also large. So there are highest energy per unit of cost or volume material. So statement I is correct

The Alnico alloy is very hard and brittle, therefore they cannot be machined. Statement II is also correct. Statement I explains above magnetic properties and statement II explain above mechanical properties of Alnico

26. **Ans: (d)**

**Sol:** All substances except diamagnetic materials exhibit permanent dipole moment.

27. **Ans: (b)**

**Sol:** Flux  $\phi = B \times A$   
 $\therefore B = \phi/A = 0.4 \text{ T}$

28. **Ans: (c)**

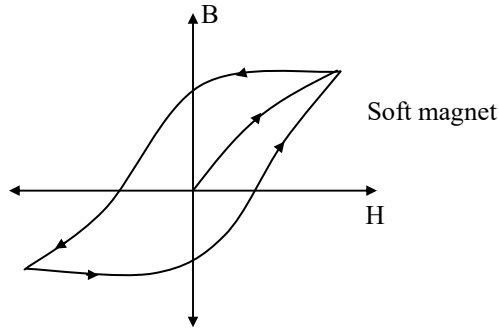
**Sol:** Curie's law for paramagnetic substances is  
$$\chi \propto \frac{1}{T}$$

29. **Ans: (b)**

**Sol:** The high permeability magnetic materials domain walls are easily moved. with small applied magnetic field.

30. **Ans: (a)**

**Sol:** Soft Iron is a soft magnetic material with narrow and tall hysteresis loop  
→ Low coercivity  
→ High susceptibility  
→ High permeability  
→ It conducts electricity also



31. **Ans: (d)**

**Sol:** Diamagnetic materials do not have permanent dipoles. They induce dipoles by applying field

32. **Ans: (c)**

**Sol:** Based on Weiss- Domain Theory, the magnetic

1. Expand at initial field. If is a reversible process
2. Rotate the dipoles in domains in the direction of fields high magnetic field. It is an irreversible process.

33. **Ans: (d)**

**Sol:** 1. Silicon steels are used in power transformer  
2. Ferrites are used in High frequency transformers  
3. Alnico is used as a permanent magnet

34. **Ans: (a)**

**Sol:** To reduce eddy current losses the core of transformer is built up on lamination.

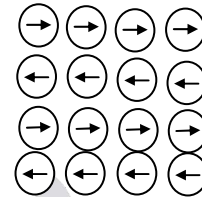
35. **Ans: (d)**

**Sol:** soft magnetic materials are not used in the fabrication of permanent magnets but hard magnetic materials are used so assertion is in correct.

Soft magnetic material domain movement is easy, where as hard magnetic material domain movement is difficult.

36. **Ans: (d)**

**Sol:** In Antiferro magnetic material, the dipoles are antiparallel with equal magnitudes so their net magnetization is zero



37. **Ans: (b)**

**Sol:** The YIG is a good soft magnetic material  
The YAG is a non-magnetic ceramic material

38. **Ans: (b)**

**Sol:** 1. Super conductor  $\Rightarrow \chi =$  Negative and very high  
2. Ferric chloride (Paramagnet)  $\Rightarrow \chi =$  Positive and small  
3. Diamond (Diamagnet)  $\Rightarrow \chi =$  Negative and small

4. Manganese oxide (Anti Ferro magnet)  $\Rightarrow$

$$\chi = \frac{C}{T + \theta} \text{ (Neel's Law)}$$

39. **Ans: (b)**

**Sol:** In paramagnetic, the susceptibility is largely dependent on temperature. Curie's Law:

$$\chi = \frac{C}{T} \text{ \& } \chi \text{ is positive and very small.}$$

40. **Ans: (d)**

**Sol:** At finite temperature magnetic dipoles in a material are randomly oriented giving low magnetization when the magnetic field H is applied, then magnetization.



- (i) increases with H  
(ii) decreases with temperature for constant H.

**41. Ans: (b)**

**Sol:** Ferrites are particularly suited for high frequency applications because of their low eddy current loss.

**42. Ans: (a)**

**Sol:** The Susceptibility of diamagnetic materials is independent of temperature.

**43. Ans: (a)**

**Sol:** Ferrites are metal oxide ( $M_n Fe_2 O_4$ ) ceramics with high magnetic flux density with minimum eddy current losses and hence they are used in inductances for high frequencies

**44. Ans: (b)**

**Sol:** Tall  $\rightarrow$  high saturation magnetization  
narrow  $\rightarrow$  low coercive field

**45. Ans: (b)**

**46. Ans: (b)**

**Sol:** The magnetic moment due to the spin of the electron is 1 Bohrmagnetron

$$(1 \mu_B) 1 \mu_B = \frac{eh}{4\pi m} = 9.27 \times 10^{-24} \frac{J}{T}$$

The effective orbital moment is present only when unpaired electrons are present in

p, d, ... etc. orbitals. [In S orbital  $\mu_l = 0$ ]

**47. Ans: (a)**

**Sol:** Eddy current loss is minimized using a ferrite core which has large resistance. Also by using laminated sheets with insulated coatings.

**48. Ans: (c)**

**Sol:** The temperature at which a conductor becomes a super conductor is called critical or transition temperature ( $T_c$ )

**49. Ans: (b)**

**Sol:** The properties of material for the core in a power transformer

1. High permeability
2. High saturation magnetization
3. High susceptibility

**50. Ans: (a)**

**Sol:** Ferrites are the modified structure of iron with no carbon. Ferrites and Garnets have high electrical conductivity than that of hard magnetic alloys. This reduces the eddy current losses.

**51. Ans: (c)**

**52. Ans: (c)**

**Sol:** Diamagnetic susceptibility is negative, small and is independent of temperature and field strength.

**53. Ans: (d)**

**Sol:** 1. Silicon steels are used in power transformer

2. Ferrites are used in High frequency transformers

3. Alnico is used as a permanent magnet

**54. Ans: (c)**

**Sol:** In ferromagnetic materials, the atomic moments are parallel. Ferromagnets become very strongly magnetized in a weak external field and may possess a spontaneous magnetic moment even in zero field.

Ferro magnetism only exists below certain temperature, the Curie temperature  $T_c$ , above which the substance becomes paramagnetic. The relative permeability of these materials is very large and positive.





**55. Ans: (a)**

**Sol:** Electrical resistivity has to high for ferrites, not for 4% Si-Fe. Which is ferromagnetic material further upon adding 4% Si coercive force and  $B_{sat}$  both decreases.

**56. Ans: (b)**

**Sol:** For transition elements like Fe, Co, Ni, the ratio of the atomic diameter to 3D orbital diameter is in the range of 1 to 1.5.

**57. Ans: (d)**

**Sol:** Structural formula for ferrites is  $AOB_2O_3$  or  $AB_2O_4$

**60. Ans: (b)**

**Sol:**

**58. Ans: (c)**

**Sol:** A. Ni-Zn Ferrite → Audio & TV transformers

B. Co – Sn alloy → Permanent Magnets

C. Yttrium-Iron-Garnet → Microwave isolation

D. Mg-Zn Ferrite → Memory core

**59. Ans: (c)**

**Sol:** Permanent magnets are hard magnets. Electromagnets are soft magnets.

Magnetic Material	Dipole arrangement	
1. Ferro magnet		All dipoles are aligned in one preferred direction and have equal magnitudes
2. Ferri magnet		Anti parallel with unequal Magnitudes
3. Anti ferro magnet		Anti parallel with equal magnitude
4. Para magnet		All the dipoles have equal magnitude with randomly oriented.

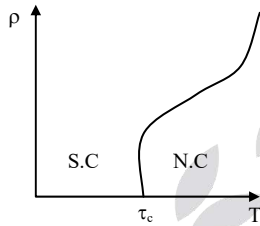


**4. Super conductors**

**Level-1**

**01. Ans: (c)**

**Sol:** Materials in which resistivity drops to zero value are called super conductors.



**02. Ans: (a)**

**Sol:**  $\chi_m = \mu_r - 1$

In super conductor  $\chi_m = -1$  (negative)  
 $\mu_0 = 0 \rightarrow$  super conductor has zero resistivity.

**03. Ans: (c)**

**Sol:** Most of the metals (Except Cu, Ag, Au, Fe...etc) are become super conducting below a certain temperature which is characteristic of the particular metal so statement I is correct

Superconducting compounds and alloys have components, which is not superconducting nature. For example in YBCO (Yttrium Barium copper oxide) is a ceramic super conductor but in that component copper is not a super conductor.

**04. Ans: (d)**

**Sol** Based on BCS Theory (Bardeen-copper-Schrieffer) the superconductor have small energy gap of 0.001eV due to the presence of copper pairs and which generate lattice vibrations.

**05. Ans: (b)**

**Sol:** Both Type I and Type II SC have infinite conductivity in super conductor state only which gets destroyed above critical temperature and magnetic field

**06. Ans: (b)**

**Sol:** In super conductor state,

$$B = \mu_0 (M + H)$$

$$\text{Susceptibility } \chi = \frac{M}{H} = -1$$

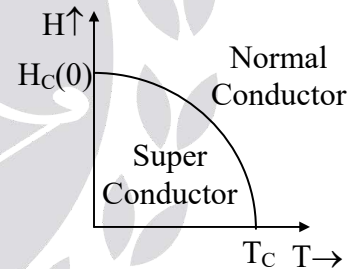
**07. Ans: (d)**

**Sol:** The critical field  $H_c$  depends on temperature

$$H_c = H_c(0) \left[ 1 - \frac{T^2}{T_c^2} \right]$$

$$\text{at } T = 0, H_c = H_c(0)$$

$$\text{at } T = T_c, H_c = 0$$



**08. Ans: (d)**

**Sol** Superconductivity of a material is destroyed by

1. Increasing the temperature above the critical temperature
2. Increasing the magnetic field above the critical magnetic field
3. Increasing the current above the critical current

**09. Ans: (c)**

**Sol:**  $\chi = \mu_r - 1$  ; for SC  $\chi = -1$  ; therefore  $\mu_r = 0$

**10. Ans: (d)**



Level-2

01. Ans: (b)

Sol: Useful superconducting materials have very low critical temperatures.

02. Ans: (c)

Sol: Isotope effect in superconductors shows that, lattice vibration (phonons) also has some role in superconductivity.

03. Ans: (c)

Sol: Type I SC are also termed as soft SC which exhibit meissner effect and silsbee's rule.

04. Ans: (a)

Sol:  $H_c(T) = H_c(0) \left[ 1 - \frac{T^2}{T_c^2} \right]$

So, as temperature is decreased below critical temperature, value of critical magnetic field increases.

05. Ans: (a)

Sol Superconductivity of a material is destroyed by

1. Increasing the temperature above the critical temperature
2. Increasing the magnetic field above the critical magnetic field
3. Increasing the current above the critical current

06. Ans: (b)

Sol: Superconductors repel magnetic field due to the Meissner effect. Near the surface of the super conductor material small magnetic current flow (without any resistance) that make an opposite magnetic field that repels field from the magnet.

07. Ans: (c)

Sol: For a SC, susceptibility  $(\chi_m) = -1$   
Relative permeability =  $1 + \chi_m = 0$

08. Ans: (d)

Sol: In a superconducting material

$$H = \frac{I}{2\pi r}$$

$H \uparrow$  when  $I \uparrow$  but below critical values of these quantities.

09. Ans: (a)

Sol Good conductors like silver, copper and gold do not show the superconductivity. Based on BCS (Bardeen-cooper-Schrieffer) theory electrons and phonons interaction leads to formation copper pairs in good conducting metals so that do not show the superconductivity.

10. Ans: (c)

Sol:  $\chi = \mu_r - 1$ ; for SC  $\chi = -1$ ; therefore  $\mu_r = 0$

11. Ans: (c)

Sol: Critical field exists only below the transition temperature.

12. Ans: (d)

Sol Superconductivity of a material is destroyed by

1. Increasing the temperature above the critical temperature
2. Increasing the magnetic field above the critical magnetic field
3. Increasing the current above the critical current

13. Ans: (c)

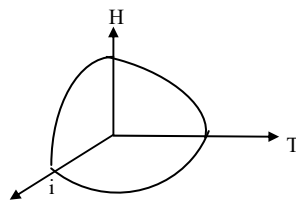
Sol The critical current density of a super conductor depends on both temperature and applied magnetic field



$$H_c = H_0 \left[ 1 - \left( \frac{T}{T_t} \right)^2 \right]$$

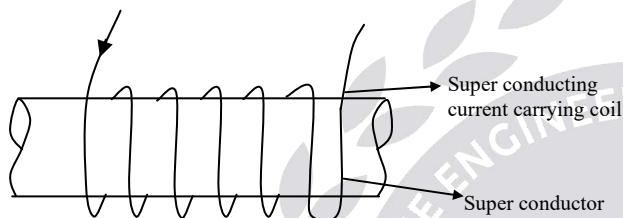
$$i_c = 2\pi R H_c$$

$$i_c = \frac{2\pi R H_c}{\pi R^2} = \frac{2H_c}{R}$$



14. **Ans: (c)**

**Sol** cryotron is a switch constructed by using superconductors



Cryotron switch is used to destroy the superconductivity

→ switching action is also characteristic of superconductors only

15. **Ans: (c)**

**Sol:** External magnetic fields are capable of destroying super conductivity. It is called critical field.

$$B_e = B_c(0) \left[ 1 - \frac{T^2}{T_c^2} \right]$$

Thus critical field  $B_e$  depends on the  $T$  of the super conductor below  $T_c$ .

16. **Ans: (a)**

**Sol:** All superconducting materials have a specific critical temperature below which only they behave as superconductors

17. **Ans: (c)**

**Sol.** In superconducting state both entropy and thermal conductivity decreases because of presence of perfectness (zero defects) in a material, so statement I is correct.

Superconductivity results basically due to zero defects in a material and not because of zero atomic vibrations.

18. **Ans: (c)**

**Sol:** The magnetic field at which a superconductor remains in its super conducting state at a temperature less than the transition temperature is less than the critical field corresponding to the given temperature.

19. **Ans: (b)**

**Sol** A superconductor is a perfect diamagnetic material because it's susceptibility is -1

A superconductor is a perfect conductor (or) zero resistivity Both assertion and reason are correct but reasons is not the correct explanation for assertion.

20. **Ans: (b)**

**Sol** To produce intense magnetic field by superconductor, the current should be less than the critical field.

$$i_c = 2\pi R H_c$$

## 5. Dielectric materials

### Level-1

01. **Ans: (a)**

**Sol:** The dielectric strength of rubber is 40000 V/mm

$$f = 50 \text{ Hz}$$

$$V = 33 \text{ kV}$$

$$\frac{33 \times 10^3}{t} = \frac{40000}{10^{-3}}$$

$$\frac{33 \times 10^3 \times 10^{-3}}{40000} = t$$



$$t = \frac{33}{40000} = 8.25 \times 10^{-4} \text{ m} = 0.825 \times 10^{-3} \text{ m}$$

$$= 0.825 \text{ mm} \approx 0.833 \text{ mm}$$

(or)

Dielectric strength of rubber is 40,000 V/mm thickness of the insulator required at

$$33\text{kV is } t = \frac{33\text{kV}}{40\text{kV}} = 0.825\text{mm}$$

**02. Ans: (b)**

**Sol:** Conductivity of insulating material is called as ionic conductivity.

**03. Ans: (d)**

**Sol:** Ferroelectric materials have already domains with permanent dipoles.

On application of electric field, they are aligned in the direction of electric field hence statement (I) is wrong. Statement (II) is correct

**04. Ans: (b)**

**Sol:** Imaginary part of dielectric constant determines amount of loss or energy absorbed per  $\text{m}^3$

**05. Ans: (a)**

**Sol:** Electrostriction  $\rightarrow$  Reverse effect of piezo electricity.

Ionic conductivity  $\rightarrow$  Conductivity of insulation

Peltier heat  $\rightarrow$  Converse of seebeck effect

Villari effect  $\rightarrow$  Converse effect magnetostriction.

**06. Ans: (c)**

**Sol:**  $\alpha_e = 4 \pi \epsilon_0 R^3$  ;

R  $\rightarrow$  Radius of the atom

**07. Ans: (b)**

**Sol:** All ferroelectric materials are piezoelectric materials but all piezoelectric materials are not ferroelectric materials.

**08. Ans: (c)**

**Sol:** A dielectric when subjected to an alternating electric field, the dielectric constant is expressed as a complex quantity  $\epsilon_r^* = \epsilon_r' - i\epsilon_r''$  where,  $\epsilon_r'$  is the real part and is  $-i\epsilon_r''$  is the imaginary part. Now the phase angle  $\tan 'd'$  which gives energy dissipated

$$\text{in a dielectric is given as } \tan \delta = \frac{\epsilon_r''}{\epsilon_r'}$$

**09. Ans: (c)**

$$\text{Sol: } \alpha_0 = \frac{P^2}{3kT}$$

Quartz displays ferroelectric behavior and quartz crystal is formed by repeating silicon tetrahedrons.

**10. Ans: (b)**

**Sol:** The  $\text{BaTiO}_3$  loose its ferroelectric property is above its Curie point.

**11. Ans: (b)**

**Sol:** Given data,

The relative dielectric constant  $\text{Al}_2\text{O}_3 = 8$

Dielectric constant for free space =  $8.854 \times 10^{-12} \text{ f/m}$

C = ?

$$C = \frac{\epsilon_0 \epsilon_r A}{d}$$

$$= \frac{8 \times 8.85 \times 10^{-12} \times 1000 \times 10^{-6}}{0.5 \times 10^{-6}} = 1.42 \times 10^{-7}$$

**12. Ans: (b)**

**Sol:** All Ferro electric materials are piezo electric but all Piezo electric materials are not Ferro electric.

**13. Ans: (a)**

**Sol:** Ferroelectric materials above the Curie temperature:





- i. It is in the paraelectric state
- ii. Its electric susceptibility is inversely proportional to its temperature
- iii. Magnitude of electric susceptibility goes down by a factor of few hundreds in comparison to the value below the Curie temperature

**14. Ans: (d)**

**Sol:** The electric displacement  $D = \epsilon E + d.s$   
 $\epsilon \rightarrow$  permittivity;  $E \rightarrow$  electric field  
 $s \rightarrow$  strain;  $d \rightarrow$  constant  
 these material called Piezo electric material.

**15. Ans: (b)**

**16. Ans: (a)**

**Sol:** The Piezo electrical properties of quartz are useful as a standard of frequency. Quartz clocks employ a crystal oscillator made from a quartz crystal that uses a combination of both direct & converse Piezo electricity to generate a regularly timed series of electric that used mark time.

**17. Ans: (b)**

**Sol:** Electronic polarization  $\rightarrow 10^{15}$  Hz  
 Ionic polarization  $\rightarrow 10^{13}$  Hz  
 Orientational polarization  $\rightarrow 10^{12}$  Hz  
 Space charge polarization  $\rightarrow 10^2$  Hz

**18. Ans: (a)**

**Sol:** Lead Zirconium Titanate can also be used in a record player

**19. Ans: (c)**

**Sol:** At high frequencies (optical) only electronic polarizability contributes. Ionic and orientational polarizabilities are not possible at optical frequencies.

**20. Ans: (b)**

**Level-2**

**01. Ans: (c)**

**Sol:** The coupling coefficient  $(K) = 0.32$   
 Output mechanical energy  $= 7.06 \times 10^{-3} \text{J}$   
 $= 7.06 \text{ mJ}$

$\therefore$  The applied electric field

$$E = (1-0.32) \times 7.06 = 4.8 \text{mJ}$$

**02. Ans: (d)**

**Sol:** The three polarization mechanism in dielectrics are electronic (bound), ionic & dipolar. Which are responsible for dielectric losses.

**03. Ans: (d)**

**Sol:** The overall mobility of a semiconductor, the present both impurity scattering ( $\mu_i$ ) and phonon scattering ( $\mu_p$ ) is  $\mu_0 = \frac{\mu_i \times \mu_p}{\mu_i + \mu_p}$

**04. Ans: (c)**

**Sol:** The aluminum oxide used dielectric in electrolytic capacitors.

**05. Ans: (b)**

**Sol:** Given data,  
 $F = e\bar{E}$   
 $= 1.6 \times 10^{-19} \times \frac{2000}{1 \times 10^{-2}}$   
 $= 1.6 \times 2 \times 10^{-19} \times 10^{-5}$   
 $= 3.2 \times 10^{-14} \text{ N}$

**06. Ans: (d)**

**Sol:** Properties of insulators

**DC uses:**

1. Insulation resistance
2. Dielectric breakdown strength

**AC uses:**

1. Dielectric losses



2. Permittivity
3. Insulation resistance
4. Dielectric breakdown strength

**07. Ans: (c)**

**Sol:** given dielectric strength is 8 kV/mm. As the thickness of the paper is 0.05 mm, breakdown occurs at 8 kV/mm × 0.05 mm = 0.4 kV

**08. Ans: (d)**

**Sol:** In a parallel plate capacitors, let the charge be held constant while the dielectric material is replaced by different dielectric materials consider as storage energy, electric field intensity and capacitance.

**09. Ans: (d)**

**Sol:** The effective Q of the equivalent electric circuit of quartz crystal is of the order is 2 lakh.

**10. Ans: (c)**

**Sol:** refractive index  $n = \sqrt{k} = \frac{c}{v}$

$$k = \left(\frac{c}{v}\right)^2 = 9$$

**11. Ans: (d)**

**Sol:** It is a related to the ratio between maximum storage energy and dielectric mean is called a quality factor.

**12. Ans: (d)**

**Sol:** Power loss or heat generated per second is

$$W = E^2 v \left[ \frac{\epsilon_r \tan \delta}{1.8 \times 10^{12}} \right] \text{ Watt/cm}^3$$

**13. Ans: (c)**

**Sol:** Boltzmann constant → electron volt/Kelvin

Permeability of free space → Henry/meter

Permittivity of free space → Farad/meter

Mobility → cm<sup>2</sup>/ volt-second.

**14. Ans: (a)**

**Sol:** The increase in applied frequency, dielectric loss in a material will increases

$$P = V^2 2\pi f C \frac{\epsilon_r''}{\epsilon_r'}$$

**15. Ans: (c)**

**Sol:** Transformer or capacitor insulation is not used askarels because they decompose easily giving out toxic gases.

**16. Ans: (\*)**

Both statements are false .

Barium titanate is ferroelectric, exhibits spontaneous polarization even in the absence of external electric field.

It has a large number of permanent dipoles even in the absence of external electric field. Its curie point is 361°K. Hence both are false

**17. Ans: (a)**

**18. Ans: (a)**

**Sol:** high humidity allows conduction and high temperature is the favorable condition chemical reactions.

**19. Ans: (a)**

**Sol: Ferro electrical materials:**

- i. all domains are lined up in the direction of applied field giving rise to saturation
- ii. if the field is reduced to zero, many domains remain aligned
- iii. the remnant polarization can be eliminated only if the material is heated above Curie temperature

**20. Ans: (b)**

**21. Ans: (a)**

**Sol:** Ceramic insulators undergo a glazing process to reduce the possibility of electric breakdown it makes the surface non-absorbent.



22. Ans: (a)                      23. Ans: (d)

24. Ans: (d)

Sol: Barium titanate & quartz is a Piezo electric material.

25. Ans: (c)

Sol: On the application of the field E, the modified field due to polarization P in solids and liquids having cubic symmetry is simplified by  $E + \frac{P}{3\epsilon_0}$ .

26. Ans: (d)

Sol: The displacement of the positively charged nucleus and the (negative) electrons of an atom in opposite directions, on application of an electric field, result in electronic polarization.

It is present in all substances, independent of temperature, proportional to volume of the atom, fastest of all four, occurs upto optical frequencies and is complete.

27. Ans: (b)

Sol:  $m\ddot{x} = -ax - 2b\dot{x} - 2E_0 \cos \omega t$

In the above equation 'm' is the mass of the electron charge cloud and not of electrons and nucleus.

'a' restoring force constant

'b' damping constant due to the emission of radiation

$m\ddot{x}$  is the force acting on the electron cloud which gets displaced from its equilibrium position; no alteration of velocity of electrons orbiting the nucleus.

28. Ans: (c)

Sol: Ionic polarizability  $\alpha_i = e^2 \omega^2 \left( \frac{1}{M_c} + \frac{1}{M_a} \right)$

29. Ans: (c)

Sol:  $\alpha = 4\pi\epsilon_0 R^3 + e^2 \omega^2 \left( \frac{1}{M_c} + \frac{1}{M_a} \right) + \frac{P^2}{3KT}$  ;

$$\frac{\epsilon - 1}{\epsilon + 2} = \frac{N\alpha}{3\epsilon_0}$$

The dielectric constant of an insulator depends on frequency of the alternative field applied and temperature.

30. Ans: (b)

Sol: Ferromagnetism → An internal molecular field  $B_m$  which is proportional to magnetization M exist at each dipole and aligns it parallel to other dipole

Semiconductor → Doping with impurity increases the electrical conductivity

Optical property of solid → The conductivity of crystalline semiconductors and dielectric increased by radiation incident.

Super conductivity → DC electrical resistivity vanishes.

31. Ans: (d)

32. Ans: (d)

## 6. Ceramics & composites

### Level-1

01. Ans: (c)

Sol: The atomic bonding in ceramics is partially ionic and partially covalent, with a predominantly ionic character.

02. Ans: (d)

Sol: Mechanical properties of fiber-reinforced composite is mainly influenced by

1. properties of constituents
2. Interface strength
3. Fiber length, orientation, and volume fraction.

03. Ans: (d)

Sol: Wrong statement about ceramics:

They contain very less number of flaws like interior pores, Surface and interior cracks.



04. Ans: (d)

Sol: Abrasives are used to wear, grind or cut other materials, which are softer, Examples are diamond, silicon, carbide, tungsten, carbide, aluminum oxide, etc.

05. Ans: (d)

Sol: Ceramics are classified according to their crystal structure as AX, AX<sub>2</sub>, ABX<sub>3</sub> and AB<sub>2</sub>X<sub>4</sub> types.

Examples under each type are given below:

AX : NaCl, CsCl, ZnS

AX<sub>2</sub>: SiO<sub>2</sub>, CaF<sub>2</sub>, PuO<sub>2</sub>, ThO<sub>2</sub>

ABX<sub>3</sub>: BaTiO<sub>3</sub>, SrZrO<sub>3</sub>, SrSnO<sub>3</sub>

AB<sub>2</sub>X<sub>4</sub>: MgAl<sub>2</sub>O<sub>4</sub>, FeAl<sub>2</sub>O<sub>4</sub>

06. Ans: (d)

Sol: Ceramics have very high hardness values; they are the hardest known materials. Examples of ceramics of very high hardness values are silicon carbide, tungsten carbide, aluminum oxide, boron nitride, quartz, etc.

07. Ans: (a)

Sol: composites are suitable for high temperature applications using Carbon-carbon composites.

08. Ans: (a)

Sol: 1. The elastic modulus of a composite increases with increasing volume fraction for any load  
2. Under transverse load, the elastic modulus of composite is very low  
3. Continuous fiber composites have high tensile strength for longitudinal load.

09. Ans: (b)

Sol: Composites in which the reinforcing fibres are long, extending over the entire length of the material are called continuous fibre composites. These composites are highly anisotropic, in the sense that their properties vary widely in different directions.

10. Ans: (a)

Sol: ceramic materials:

1 They are inorganic substances

2 They are brittle

3 They are good thermal insulators

Level-2

01. Ans: (a)

Sol: The structure of various types of silicates can be understood in terms of the arrangements of SiO<sub>4</sub> tetrahedron. Silicon is tetravalent and oxygen is divalent. Thus SiO<sub>4</sub> tetrahedron has a negative charge of 4 units. It is denoted by (SiO<sub>4</sub>)<sup>4-</sup>.

02. Ans: (d)

Sol: Ceramic materials are refractories, abrasives & Glasses. Garnets is a composite material

03. Ans: (c)

Sol: If the radius ratio = 0.225, a more stable configuration is possible with four anions bonding with a cation as shown below. This configuration called the tetrahedral configuration, is stable for 0.225 < x < 0.414. Here the cation occupies the void created by four anions forming a tetrahedral structure.

04. Ans: (a)

Sol: Cermets are large particle composites in which ceramic particles are embedded in a metal matrix.

These cermets are extremely hard materials and they are extensively used as cutting tools.

05. Ans: (b)

Sol: Concrete is a typical example of large particle composite in which the cement matrix is mixed with particulate of sand and gravel.



06. Ans: (c)

Sol: The three kinds of breakdowns possible in solid dielectrics are electrothermal, purely electrical and electrochemical.

## 7. Nano materials

### Level-1

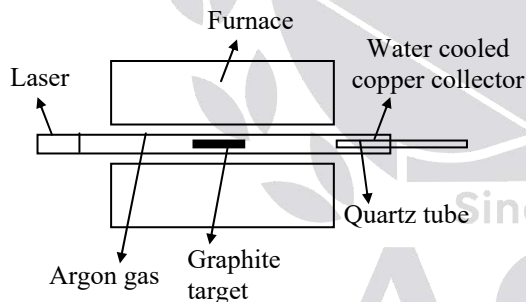
01. Ans: (b)

Sol: The nature of the bonding of a nanotube is described by applied quantum chemistry, specifically, orbit hybridization. Nanotubes are composed entirely of  $sp^2$  bonds.

02. Ans: (d)

Sol:

*i. Laser Evaporation Method* :The experimental arrangement for synthesizing carbon nanotubes by laser evaporation is as shown in the fig below.



The graphite target contain small amounts of cobalt and nickel that act as catalytic nucleation sites for the formation of the nanotubes.

An intense pulsed laser beam is incident on the target, evaporating carbon from the graphite, the argon then sweeps the carbon atoms from the high temperature zone to the colder copper collector on which they condense into nanotubes. Tubes 10-20mm diameter and 100  $\mu\text{m}$  long can be made by

this method. This method produces tubes with closed ends.

*(ii) Carbon Arc Method:* A potential of 20-25V is applied across carbon electrodes of 5-20  $\mu\text{m}$  diameter and separated by 1mm at 500 torr pressure of flowing helium. Carbon atoms are ejected from the positive electrode and form nanotubes on the negative electrode. As the tubes form, the length of the positive electrode decreases, and a carbon deposit forms on the negative electrode. This method produce tubes with closed ends.

03. Ans: (c)

Sol: The tensile strength of carbon nanotubes is about 45 billion Pascal's. High strength steel alloys break at about 2 billion Pascal's. Thus carbon nanotubes are about 20 times stronger than steel.

04. Ans: (c)

Sol: Depending on the no.of dimensions If all 3 dimensions are in 'nm' range it is termed as quantum dots (nano particles (or) clusters)

05. Ans: (b)

Sol: Fe, Co and Ni are ferromagnetic in bulk form  
In Nano scale, they become super paramagnetic Both statements are correct

06. Ans: (d)

Sol: Alkali metals like Na and K are paramagnetic in bulk form their nano clusters are ferro magnetic.

07. Ans: (d)

Sol: The optical properties of nano materials are different from that of corresponding bulk samples because of

- (i) Quantum confinement effect of charge carriers in nano materials





- (ii) Enhanced surface to volume ratio in nano materials
- (iii) Charge and energy transfer is more efficient at the nano level

**08. Ans: (d)**

**Sol:** Nano particles exhibit more magnetism than the particles of the Bulk because of

- (i). Quantum confinement in the Nano particles
- (ii). large surface area to volume ratio of the nano particle
- (iii). Smaller value of the mean coordination number in the nano particle

**09. Ans: (d)**

**Sol:** There are two different approaches of nanomaterial fabrication. One is the top – down approach and the other is the bottom – up approach. In top down technique generally a bulk material is taken and machined it to modify into the desired shape and product. Examples of this type of technique are the manufacturing of integrated circuits using a sequence of steps such as crystal growth, lithography, etching, ion implantation, etc. For nanomaterial synthesis ball – milling is an important top down approach, where microcrystalline structure are broken down to nanocrystalline structures, but original integrity of the material is retained.

**Level-2**

**01. Ans: (a)**

**Sol:** Generally, carbon nanotubes form as a mixture of semiconducting and metallic tubes in the ratio 2:1. The diameter and the chirality of a tube determine the conducting behavior of the tube. Chirality describes the manner in which the graphite sheet is rolled with respect to the axis vector. The metallic nanotubes have the armchair structure.

**02. Ans: (a)**

**Sol:** To produce single walled nanotubes, a small amount of cobalt, nickel, or iron is incorporated as a catalyst in the central region of the positive electrode. This method can produce single walled nanotubes of diameters 1-5nm with a length of 1  $\mu\text{m}$ .

SWNTs are preferable using arc discharge method, the anode has to be doped with metal catalyst, such as Fe, Co, Ni, Y or Mo.

**03. Ans: (c)**

**Sol:** Chemical Vapor Deposition Method involves decomposing a hydrocarbon gas such as methane ( $\text{CH}_4$ ) at  $1100^\circ\text{C}$ . As the gas decomposes, carbon atoms are produced. Carbon atoms then condense on a cooler substrate that contains various catalysts such as iron. This method produced tubes with open ends.

**04. Ans: (b)**

**Sol:** Sol - gel is a wet – chemical – based self-assembly process for nanomaterial formation. The Sol-gel process, as the name implies, involves the evolution of networks through the formation of a colloidal suspensions (sol) and gelation of the sol to form a network in a continuous liquid phase (gel).

Once the gel is formed, there are several ways to convert this gel (inorganic network to the desired solid form. Depending on the deposition and drying processes or conditions, this gel can be converted into various forms such as aerogel, xerogel, gelled spheres, nano-powders, thin film coatings, nanostructured layers, etc.

**05. Ans: (b)**

**Sol:** In metal nano clusters the electrical conductivity gets enhanced these statement is wrong



**06 Ans: (b)**

**Sol:** The electric conductivity of a nano metallic sample is smaller than that of the corresponding bulk samples because.

- (1). The density of states of conduction and valance bands decreases in Nano sample.
- (2). The energy gap between the conduction and valance bands increases in the nano sample

**07. Ans: (b)**

**Sol:** The reduction in the particle size in the case of semiconductors results in the increased in the bandgap which results in the shift of the light absorption towards in the high-energy region (blue shift). In addition, the band edge position of valance and the conduction bands are stabilized and destabilized respectively. The rate of recombination of photo excited electron hole pair is greatly reduced.

