ESE Mains Achiever's Study Plan

Electronics & Communication Engineering

Material Science

1. Explain Schottky and Frenkel defects with the help of suitable diagram.

Sol. (i) Frenkel defect: If an atom or ion is displaced from its normal lattice point (thereby creating a vacancy) and it occupies an interstitial site, the vacancy - interstitial pair formed is called Frenkel defect. This kind of defect is usually formed in ionic crystals only. It is rare in the normal close packed structure. (see figure 1).
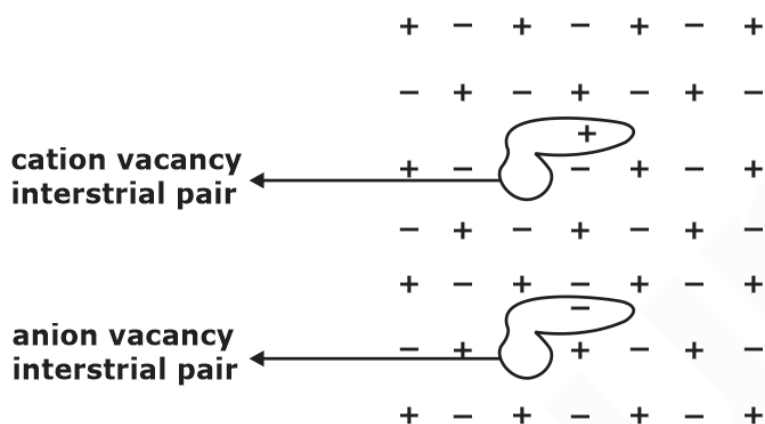

Figure 1

(ii) Schottky defect: In an ionic crystal, consider that an anion vacancy is created. Then to maintain charge neutrality, a cation vacancy will be created. The anion cation vacancy pair is called schottky defect. (see figure 2).
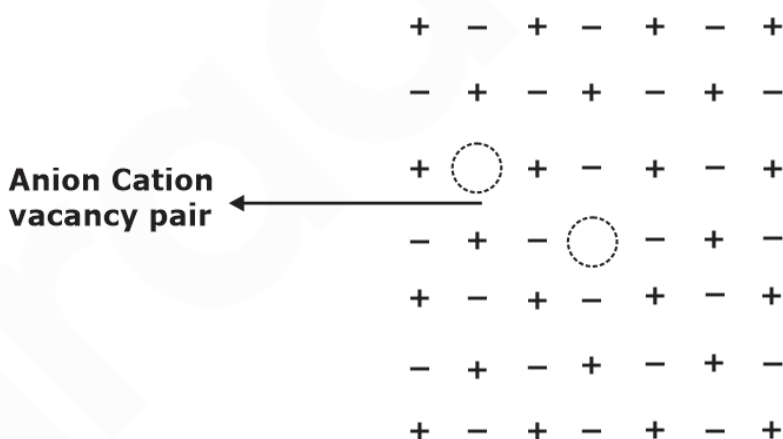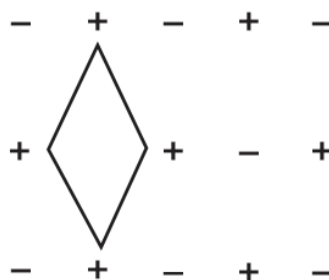

Figure 2

2. What type of defect causes F-centres in a crystal?

Sol. F-centre: The simplest colour centre is the F-centre. The name comes from German word for colour, "Farbe". It is usually produced by heating crystal in excess alkali vapour or by x irradiation.

F-centre has been identified by electron spin resonance as an electron bound at a negative ion vacancy. This occurs in alkali halides as well as in other ionic crystals.

When white light passes through the crystal, a fraction of the light corresponding to a narrow frequency region is absorbed, and the transmitted light is there-fore coloured. Hence the name colour centre.

3. Discuss the variation of Fermi level in n-type and p-type semiconductor with the concentration of impurity.

Sol. n-type semiconductors: Consider a pure Si specimen. In this the silicon atoms are tetrahedrally bonded to 4 other silicon atoms as the structure of Si is that of diamond. Let an impurity from the V group such as phosphorous be introduced into silicon. The phosphorous atoms substitute for the Si atoms. Phosphorous has 5 valence electrons.

Four of these form the covalent bonds with the 4 neighbouring atoms. The fifth electron of P is left without a bond. This will be revolving around the phosphorous atom.

The energy of this electron, lies below the conduction band (see figure below), at E_D. On bringing to room temperature (300K) most of these electrons jump to the conduction band as the energy difference is very small. Since the impurities of the fifth group are donating their electron to conduction band they are called donor impurities. The energy level ED is called donor energy level. As the number of free electrons provided by these impurities are very large in comparison with the intrinsic charge carriers, the semiconductor is called n-type.

The expression for the Fermi energy E_F is given by

$$E_F = E_c - kT \ln\left(\frac{N_c}{N_D}\right)$$

Where N_C is the density of energy states in the conduction band and N_D is the donor atoms concentration.

For light doping, $N_D < N_C$ Hence E_F lies in the forbidden band.

As a result the Fermi level is shifted towards the conduction band edge.

On increasing the concentration, the

Fermi level moves further towards the conduction band edge. On heavy doping, such that $N_D > N_C$, we find that $E_F > E_C$; the Fermi level moves inside the conduction band.

p-type semiconductors: In a pure silicon specimen let us introduce an impurity from the Ill group, such as Al.

The valency of Al is 3. Hence it has only 3 valance electrons. Therefore it forms covalent bonds with 3 silicon atoms.

Hence the fourth silicon of the tetrahedral bonding has its bond broken.

Thus the fourth electron of the silicon atom is now left without a bond. When the energy of this 4th electron is calculated it lies above the valence band edge, shown by E_A in the figure. It is called acceptor energy level. As a result of doping, the Fermi level moves towards the valence band edge. As the energy difference between E_V and E_A is small, most of the electrons of the silicon atoms whose bonds are broken as result of introducing the Al atoms jump to the acceptor level. This leaves an equal number of holes in the valence band, without creating an electron in the conduction band. As a result the majority of the charge carriers in this specimen are holes and hence it is called a p—type semiconductor.

The expression for the Fermi energy E_F is given by

$$E_F = E_v + kT\ln\left(\frac{N_v}{N_A}\right)$$

Where N_V, is the density of energy states in the valence band and N_A is the acceptor atoms concentration.
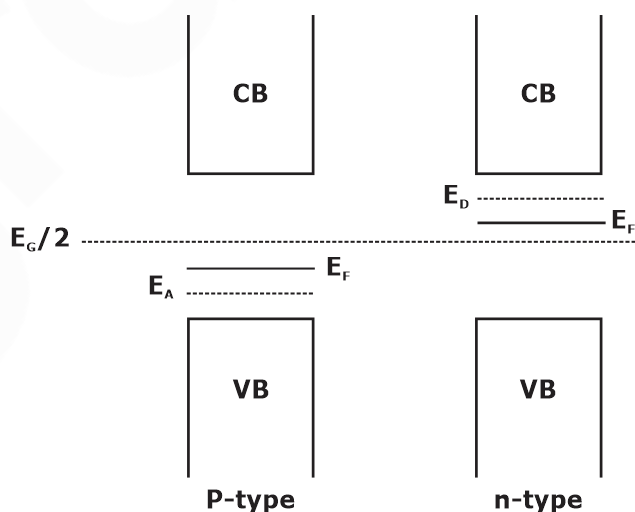
For light doping, $N_A < N_V$. Hence E_F lies in the forbidden band.

As a result the Fermi level is shifted towards the valence band edge.

On increasing the concentration, the

Fermi level moves further towards the Valence band edge.

On heavy doping, such that $N_A > N_V$, $E_F < E_V$, the Fermi level moves inside the valence band.

4. Explain how ferro, anti ferro and ferrimagnetic substances are distinguished. Give some examples.

Sol. Ferromagnetic Materials: These materials are characterized by the property of spontaneous magnetization.

They possess a large amount of magnetization even in the absence of external magnetic field. They have very large susceptibility. This is due to a very large amount of parallel alignment of spins in the valence shell (see figure 1).

This is possible only in d and 'f' block. Amongst the d—block elements only Fe, Co and Ni and in the f-block elements only Gd and Dy have large unpaired spins and hence they occur as ferromagnet. Their electronic configuration and effective magnetic moment are given below.

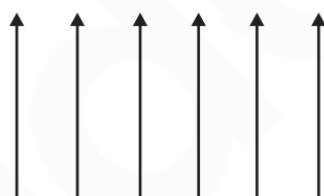| Element	Electronic Configuration	Effective Magnetic Moment per atom in Bohr magnetion
Fe	$4s^2 3d^6$	2.22
Co	$4s^2 3d^7$	1.71
Ni	$4s^2 3d^8$	0.61
Gd	$6s^2 4f^8$	7.10

Figure 1

Antiferromagnetic Materials:

Antiferromagnetism is characterised by an equal and antiparallel alignment of spins (see figure 2) in the molecule so that the net magnetic moment is zero. It was first observed in MnO by Bizette, Squire and Tsai in 1938. The crystal structure of MnO is similar to that of NaCl, i.e., rocksalt.
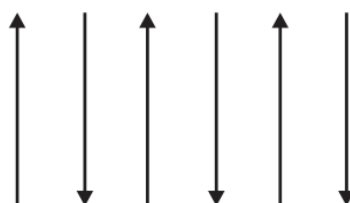

Figure 2

The cations occupy the lattice points of an F.C.C. lattice while anions occupy those of another F.C.C. lattice.

The crystal structure is made up of two inter penetrating F.C.C. lattices. The spins of all cations are pointing in one direction while those of anions are exactly anti-parallel. This results in net zero magnetic moment. But on increasing the temperature the susceptibility also increases and reaches a maximum. On further increasing the temperature the susceptibility starts decreasing as shown in figure 3. The temperature at which the susceptibility is maximum is called Neel temperature T_N. This is characteristic of any anti ferromagnetic material.

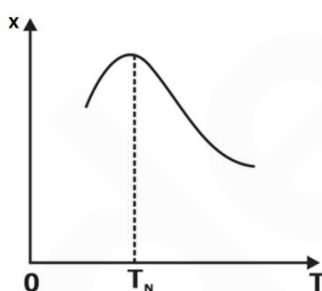| Substance	$T_N(°K)$	$\theta(°K)$
MnO	116	610
MnS	160	528
FeO	198	570
CaO	291	330

Figure 3

Ferrimagnetism - Ferrites:

Ferrimagnetic materials are characterized by unequal and anti-parallel spin magnetic moments such that they possess a net magnetization even in the absence of external magnetic field (see figure 4). In this respect the materials behave like ferromagnet. They are also called ferrites. These substances are mixed oxides and have the general formula $MO.Fe_2O_3$. M is a divalent cation such as Mn, Fe, Ca, Zn etc.,

For example magnetite, the ore of iron is a ferrite and is a compound of ferrous and ferric oxides Fe_2O_3 & FeO viz,. The molecule of magnetite consists of one Fe^{2+} ion, two Fe^{3+} ions and four O^{2-} ions. While O^{2-} ions do not contribute to the magnetic moment, only Fe^{2+} and Fe^{3+} ions contribute to magnetic moment. The crystal structure of ferrite is called inverse spinel. It is a close packed structure. The unit cell of the ferrite contains 32 oxygen ions 16 Fe^{3+} ions and 8 divalent metal ions (in this case Fe^{2+} ions). The inverse spinel structure has 16 octahedral void spaces and 8 tetrahedral void spaces. Out of the 16 Fe^{3+} ions, half of them occupy the eight tetrahedral sites and rest octahedral sites. 8 Fe^{2+} ions occupy the remaining eight octahedral sites (see figure 5).

Figure 4

Fe²⁺   Fe³⁺

··· ⊗ ············· ⊗ ········ Octahedral
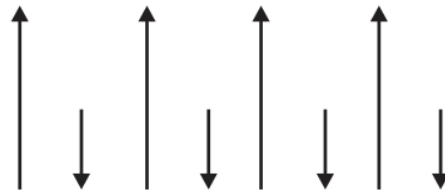
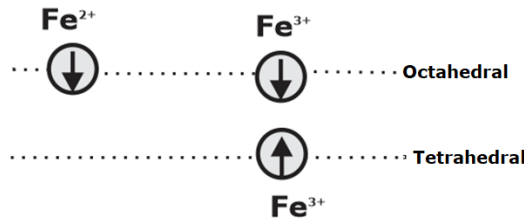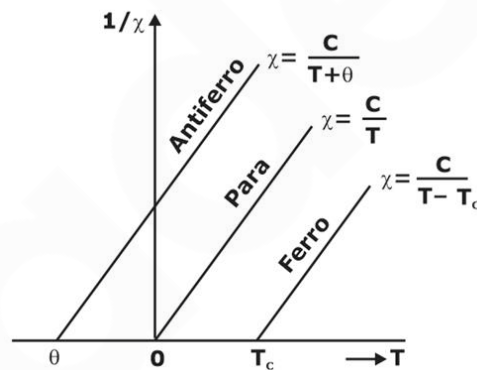··················· ⊕ ········ Tetrahedral

Fe³⁺

Figure 5

The spins of Fe^{3+} ions in the octahedral and tetrahedral sites are oppositely directed and hence they get cancelled. The magnetic moment of the ferrite molecule therefore, arises only from the divalent metal ion and this leads to spontaneous magnetization.

Ferrites also obey Curie—Weiss law and show hysteresis behaviour.

5.   Distinguish between Type I and Type II superconductors

Sol.   The superconductors are distinguished into two categories as Type I and Type II based upon their response to external magnetic field.

When the type I superconductor is subjected to a slowly increasing magnetic field the flux suddenly penetrates into the entire specimen at critical magnetic field. And the specimen is transformed into a normal conductor at this unique critical magnetic field. The superconductor is then said to obey Meissner effect exactly. It was stated that a super conductor is a perfect diamagnet with susceptibility being equal to -1. The ratio of intensity of magnetization (I) to the field strength H is called susceptibility. For a perfect diamagnet, X = - 1 = I/H

$$I = -H$$
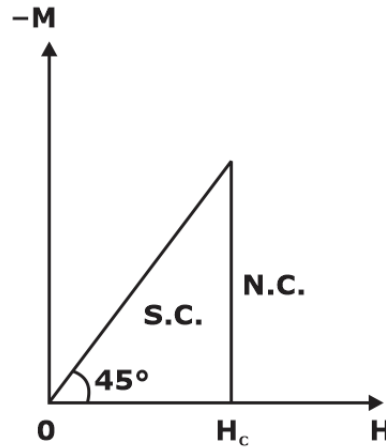
Therefore a plot between H and -M must be a straight line with slope 1 till the critical magnetic field. This is shown in the figure 1. When the applied field exceeds the critical magnetic field, the specimen becomes a normal conductor and the susceptibility becomes negligibly small and the slope of the graph will be almost zero.

When a type II superconductor is subjected to an external magnetic field, the flux does not penetrate until a certain critical field H_{c1}, is reached. But the penetration progresses gradually and it is complete at a field H_{c2}. The specimen is converted to a normal conductor for $H > H_{c2}$.

H_{c1} is called the lower critical field and H_{c2} is called the upper critical field. Below H_{c1} the specimen is a superconductor and above H_{c2} it is a normal conductor.

Between H_{c1} and H_{c2} the specimen is said to be in a mixed state or vortex state. Thus the plot between -M and H is a straight line with slope 1 till H_{c1}. As the penetration of flux commences the magnetization starts decreasing gradually and becomes zero at H_{c2} which is shown in figure 2. We say that Type II superconductors do not obey Meissner effect.
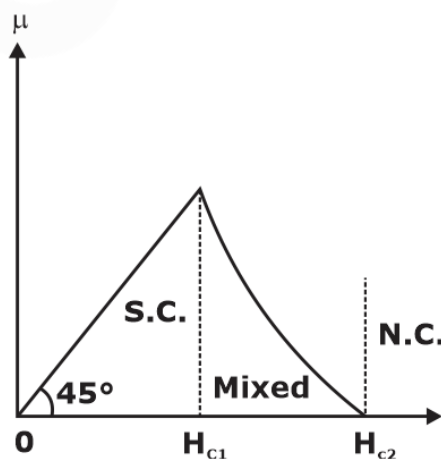
The Type I superconductors are also called soft because the critical field is about 10^4 A/rn. Type II superconductors are also called hard superconductors as the upper critical field is of the order of 10^8 A/m.

6. Write a note on orientation polarization.

Sol. Diatomic molecules formed from two different atoms and non-linear, asymmetric polyatomic molecules (e.g. H_2O, CH_3Cl, etc) carry an electric dipole moment even in the absence of an electric field, Such molecules are called polar molecules. In liquids and gases and to a lesser extent in solids the molecules possess permanent electric dipole moment. But in the absence of an external electric field
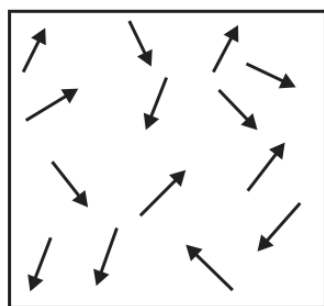
E=0
Figure (a)
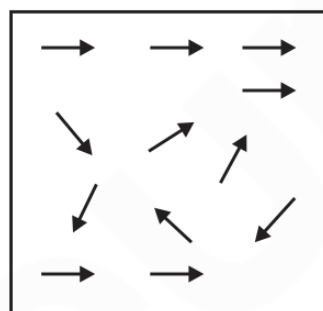
E≠0
Figure (b)

these tiny molecular dipoles (shown by arrows in the figure(a) are randomly oriented and hence the resultant moment is zero. When an electric field is applied these dipoles try to orient in the direction of the electric field due to the torque exerted by the electric field. This results in inducing a net dipole moment in the dielectric. Since the polarization of this substance is due to the orientation of the molecules, it is called orientational polarization. Orientation polarization is analogous to Para magnetism in magnetic materials. We can show that the orientation polarizability is given by $a_0 = (\mu^2/3kT)$

Where μ-the dipole moment of the molecule; k - Boltzman constant,

T - temperature of the material. It is also dependent upon the temperature.

7. Distinguish between Piezo electricity and electrostriction.

Sol. An applied electric field induces dipole moments in atoms or ions, and generally displaces ions relative to each other. Consequently, the dimensions of a specimen undergo slight changes. Mechanical stresses also change the dimensions of a specimen but in general such changes do not produced a dipole moment. In other words, in most materials dielectric polarization produces a mechanical distortion, but a mechanical distortion does not produce polarization.

This electrostriction. In purely electro strictive materials, the mechanical deformation produced by a polarization in a given direction; i.e., mechanical changes can be expressed as a series expansion containing only terms with even powers of R This material contains a centre of symmetry;

In electrostriction, the strain produced in the sample is directly proportional to E^2.

There are solid dielectric materials, however, for which the sign of a mechanical deformation produced by a polarization P changes when the direction of the polarization is reversed. Such mechanical deformations then contain at depends upon an odd power of P. These materials do become polarized upon application of mechanical stress and are called piezoelectric; they are of practical importance because they permit conversion of mechanical into electrical energy and vice versa. This material lacks a centre of symmetry, and this is a requirement for a piezoelectric material.

In Piezoelectricity the strain produced in the sample is directly proportional to E.

8. Write a brief note on applications of piezoelectric materials.

Sol. (i) Piezo-ignition system.

(ii) Pressure gauges and transducers.

(iii) Ultrasonic imaging.

(iv) Small sensitive microphones.

(v) Piezoelectric actuators for pressure control movements in Atomic Force Microscope.

(vi) Powerful Sonars.

9. What are the important properties of Ceramics?

Sol. Properties:

(i) Brittle;

(ii) Very high melting point

(iii) Not attacked by acids;

(iv) non corrosive;

(y) Good electric and thermal insulation

(vi) Very large dielectric constant;

10. What are the advantages of ceramics or other materials.

Sol. Ceramics offer many advantages compared to other materials.

(i) They are harder and stiffer than steel;

(ii) More heat and corrosion resistant than metals or polymers;

(iii) Less dense than most metals and their alloys;

(iv) Their raw materials are both plentiful and inexpensive.

(v) They display a wide range of properties which facilitate their use in many different product areas.

(vi) They have good dielectric properties.

11. Differentiate between Thermoplastic and Thermosetting polymers.

Sol.

	Thermosetting polymer	Thermoplastic polymer
1.	They have three dimensional network of primary covalent bonds with cross-linking between chains.	They are linear polymers without cross-linking and branching
2.	They are more stronger and harder than thermoplastic resins.	They are comparatively softer and less strong.
3.	Once hardened and set they do not soften with the application of heat.	They can be repeatedly softened by heat and hardened by cooling.
4.	Objects made by thermosetting resins can be used at comparatively higher temperature without damage.	Objects made by thermoplastic resins cannot be used at comparatively higher temperature as they will tend to soften under heat.
5.	They are usually supplied in a monomeric or partially polymerized form in which they are either liquid or partially thermo-plastic solids.	They are usually supplied as granular materials.
6.	It is difficult to fill an intricate mould with such plastics.	They can fill the complicated mould quite easily.
7.	They cannot be recycled.	The scrap again recycled and thus they are economical.
	Uses: Telephone receivers, electric plugs, radio & TV cabinets, camera bodies, automobile parts, circuit breaker switch panels etc.	Uses: Toys, combs, toilet goods, photographic films, insulating tapes, hoses, electric insulation, etc.

12. Explain Top - Down and Bottom — up techniques of fabrication of nano materials.

Sol. Fabrication of Nanomaterials

There are two approaches for the fabrication of nano materials such as

(i) Top - Down approach

(ii) Bottom up approach.

(i) In the Top — Down approach we start from a bulk material and gradually reduce to nano size. Mechanical attrition is a typical example of 'top down' method of synthesis of

nanomaterials, where the material is prepared by the structural decomposition of coarser-grained structures as the result of severe plastic deformation. This has become a popular method to make nanocrystalline materials because of its simplicity, the relatively inexpensive equipment needed, and the applicability to essentially the synthesis of all classes of materials. The major advantage often quoted is the possibility for easily scaling up to tonnage quantities of material for various applications.

Similarly, the serious problem that is usually cited is the contamination from milling media and/or atmosphere.

(ii) In the Bottom - Up approach, nano material is grown by assembling atom by atom similar to assembling building blocks.

These methods were originally developed for the fabrication of integrated circuits, VLSI, microprocessors, etc.

They are:

1. Lithography

2. Epitaxial Technique

3. Chemical Vapour Deposition

4. Pulsed Laser vaporization

5. Electrochemical Deposition

13. Write a note on some important applications of nano materials.

Sol. Nanomaterials having wide range of applications in the field of electronics, fuel cells, batteries, agriculture, food industry, and medicines, etc... It is evident that nanomaterials split their conventional counterparts because of their superior chemical, physical, and mechanical properties and of their exceptional formability.

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