



- Answer all the following question
- Illustrate your answers with sketches when necessary
- No. of questions: 4 in two pages
- Total Mark: 200 Marks

Question (1) (50 marks)

(A) Give short notes on: **(15 marks)**

(i) Polycrystalline solids.

Answer:

In which the regularity of the atoms extends over only a small part of the material. In this case the material is comprised of many small crystals or **grains**. These grains have different crystallographic orientation. There exist atomic mismatch within the regions where grains meet. These regions are called **grain boundaries**.

(ii) Hydrogen bond formation

Answer:

A hydrogen bond is the attractive interaction of a hydrogen atom with an electronegative atom (e.g. nitrogen, oxygen or fluorine). The important feature of the hydrogen bond which is termed “polar covalent bond” comes according to the following explanation:

“When hydrogen atoms are joined with a small atom of high electro-negativity (such as nitrogen, oxygen or fluorine), the partial positive charge on the hydrogen is highly concentrated because of its small size.”

The solid materials with hydrogen bond are much like ionic solids in properties except that the hydrogen bond is not strong and is much weaker than covalent or ionic bonds. The binding energies are of $\sim (0.5 \text{ eV})$ per molecule and hence hydrogen bonds are not strong. The most important characteristics of the hydrogen-bond crystals are:

Considerably weak.

Have permanent electric dipole moment.

Have melting and boiling points higher than other nonmetallic hydrates

(iii) Thermoplastic and thermosetting materials.

Answer:

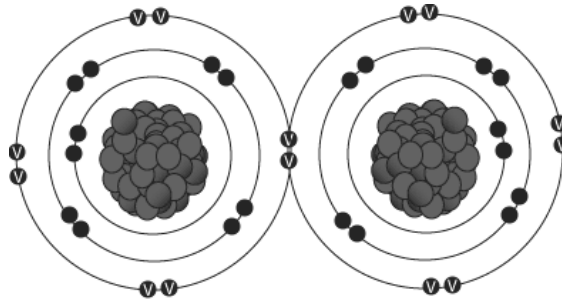
Thermoplastic materials can be easily remelted for forming or recycling and thermosetting material cannot be easily remelted. In thermoplastic materials consist of long chainlike molecules. Heat can be used to break the van der Waal forces between the molecules and change the form of the material from a solid to a liquid. By contrast, thermosetting materials have a three-dimensional network of covalent bonds. These bonds cannot be easily broken by heating and, therefore, can not be remelted and formed as easily as thermoplastics.

(B) Compare the main characteristics of covalent and ionic crystals?

(15 marks)

Answer:

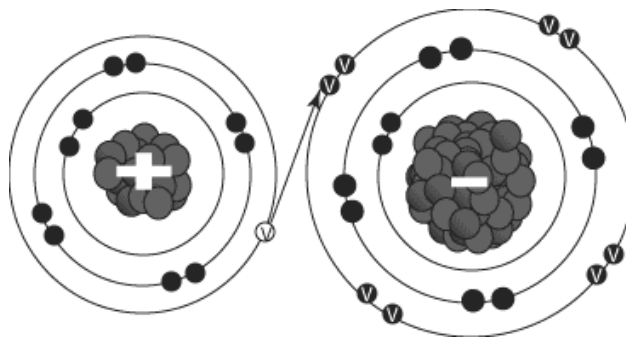
1. Covalent Bond



In *solid materials with covalent bonds*, the binding energies are of ~ 10 eV per molecule and hence covalent bonds are very strong. Generally, solid materials with covalent bonds:

- Are very hard because bond is strong and particles cannot easily slide past one another.
- Are good insulators because there are no free electrons or ions.
- Are transparent because their electrons are not moving from atom to atom and less likely to interact with light photons.
- Are brittle and tend to cleave rather than deform because bonds are strong.

1. Ionic Bond



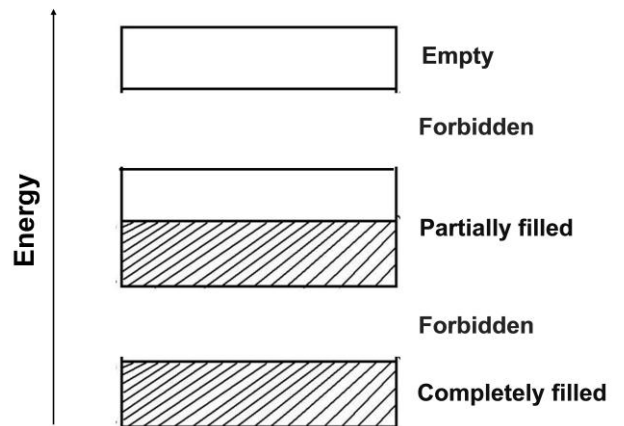
In *solid materials* with ionic bonds, the binding energies are of $\sim (5 - 10)$ eV per molecule and hence ionic bonds are relatively strong. Solids with ionic bonds:

- Are hard because bond is strong and particles cannot easily slide past one another.
- Are good insulators because there are no free electrons or ions (unless dissolved or melted).
- Are brittle and tend to cleave rather than deform because bonds are strong.
- Are transparent because their electrons are not moving from atom to atom and less likely to interact with light photons.
- Have high melting and boiling point because ionic bonds are relatively strong.

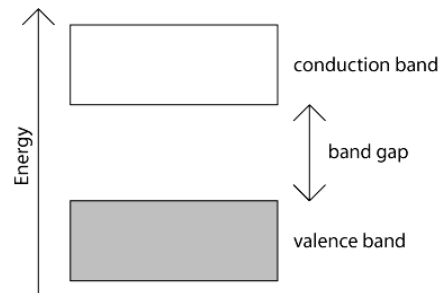
(C) Discuss the theory of energy bands within solid materials then differentiate clearly between conductors, insulators and semiconductors? **(20 marks)**

Answer:

In case of a single isolated atom an electron in any orbit has definite energy. When atoms are brought together and combine to form molecules as in solids, an atom is influenced by the forces from other atoms. Hence an electron in any orbit can have a range of energies rather than single energy. The range of the energetic levels of atoms is represented by a near-continuum of levels called *energy band*.

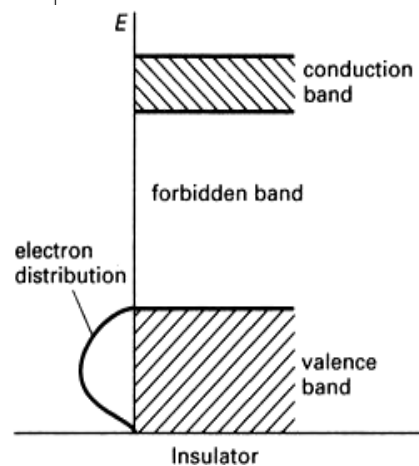


The electrons that contribute to the electrical conduction occupy the higher (partially filled) energy band which is called *the conduction band*. The highest energy band that is fully occupied with electrons is called *the valence band*. The Valence band and conduction band are separated by an energy gap in which no electrons normally exist this gap is called the *forbidden gap*.



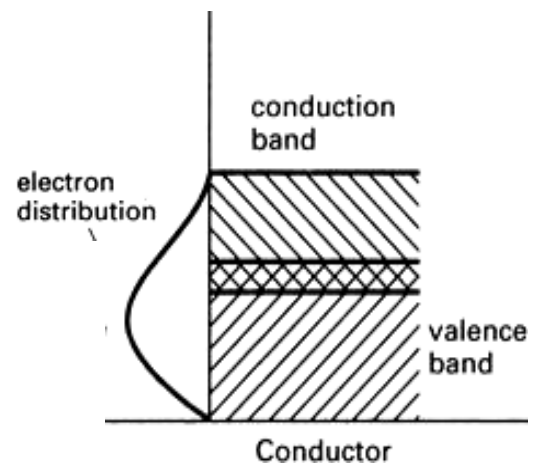
Insulators

In case of insulators, the forbidden energy gap is extremely high. On the other hand its valence band is fully filled with the electrons, whereas its conduction band is empty. For example, in diamond, the approximate value of forbidden energy gap is nearly 6 eV. In normal case, electrons would not acquire enough energy (thermally or optically) to cross the large energy gap of such materials. Thus electrons can not jump into the conduction band, and as a result these materials are insulators.



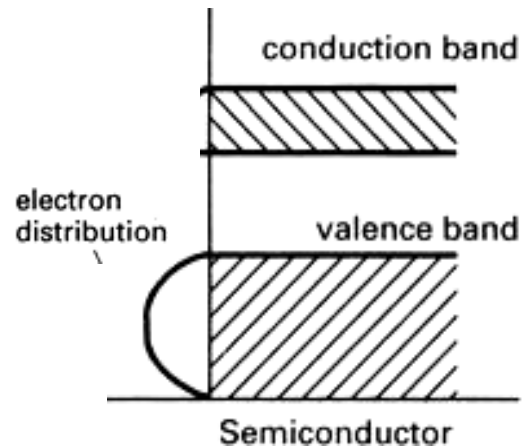
Conductors

In case of metals, electrons fill the conduction band partially. The overlapping of both the bands (i.e. valence and conduction band) also takes place. For example, iron, copper and all other metals show that no forbidden energy gap is present. Consequently, there is no energy gap to cross in order to reach the conduction band, and any energy that is added to the electron is sufficient to propel it into the conduction band. There are many electrons that are free to move about a conductor, so it is very easy for current to flow if an external electric field is applied.



Semiconductors

In case of semiconductors the conduction band is empty and the valence band is fully filled with electrons. The energy gap is very small. This energy gap is nearly of 1eV. For example, in silicon and germanium the energy gap is nearly 1.1 eV and 0.72 eV respectively. At normal temperatures, the thermal (or optical) energy is sufficient to propel some electrons from the valence band into the conduction band, allowing some electrons to be free to conduct current. The number of free charge carriers increases with supplied energy, so the conductivity of a semi-conductor can be manipulated by outside potentials.



Question (2) (50 marks)

(A) Compare the main characteristics of amorphous and crystalline solids?

(20 marks)

Answer:

Solids with amorphous structure share the following common properties:

- These solids do not have long range of periodicity in arrangement of atoms.
- Amorphous solids do not have characteristic geometrical shape.
- When amorphous solids are rotated about an axis, their appearance will change.

This shows that they are *unsymmetrical*.

- Physical properties of amorphous solids are the same in different direction.

i.e. amorphous solids are known as *Isotropic*.

- They don't have particular melting point.

That they melt over a wide range of temperature.

- Amorphous solids don't break at fixed cleavage planes.

i.e. they break into two pieces with irregular surface

crystalline solids have the following fundamentals properties:

- Crystalline solids exist in a regular, orderly arrangement.
- Crystalline solids have characteristic geometrical shape.
- When crystalline solids are rotated about an axis, their appearance does not change.

This shows that they are *symmetrical*.

- Physical properties of crystalline solids are different in different directions.

i.e. crystalline solids are known as *Anisotropic*.

- They have sharp melting point.

- They have a definite heat of fusion.

- Crystalline solids break along particular direction at fixed cleavage planes.

i.e. they break into two pieces with plane surfaces

(B) Discuss the main features of face-centered cubic (FCC) and body-centered cubic (BCC) structures of crystal lattice? **(15 marks)**

Answer: See the Text Book Pages 52-54

(C) Sodium has atomic mass of 22.95 g/mole. At room temperature; it has a density of 0.971 g/cm³. If Sodium crystallizes with a Body-centered cubic structure, Find:

i) The edge length of the unit cell of Sodium.

ii) The radius of a Sodium atom.

[Avogadro's number = 6×10^{23} atom/mole]

(15 marks)

Answer:

$$n = 2$$

$$\rho = 0.971 \text{ g/cm}^3$$

$$A = 22.99 \text{ g/mol}$$

Avogadro's number = 6×10^{23} atom/mole

$$\rho = \frac{nA}{V_c N_A}$$

$$0.971 = \frac{2 \times 22.99}{6 \times 10^{23} (a^3)}$$

$$a = 4.29 \times 10^{-8} \text{ cm}$$

$$\text{ii) } a = 4R/\sqrt{3} \quad (\text{BCC})$$

$$4.29 \times 10^{-8} = 4R/\sqrt{3}$$

$$R = 1.86 \times 10^{-8} \text{ cm}$$

Question (3) (50 marks)

(A) A piece of unknown metal is found to have lattice parameters as: $a \neq b \neq c$ and $\alpha = \beta = \gamma$. Based on this information, Determine: **(15 marks)**

(i) The type of this crystal system?

Answer: Orthorhombic

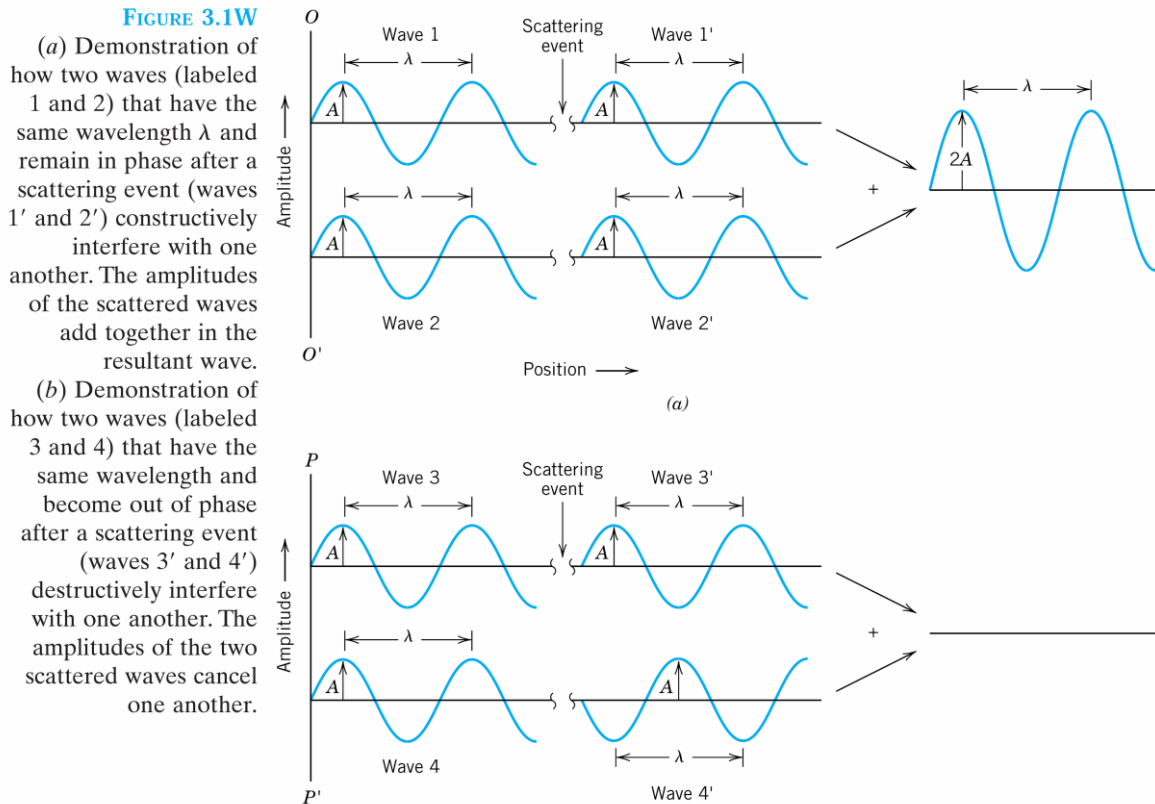
(ii) What are its Bravais lattices?

Answer: Simple, Body-centered, Base-centered and Face-centered

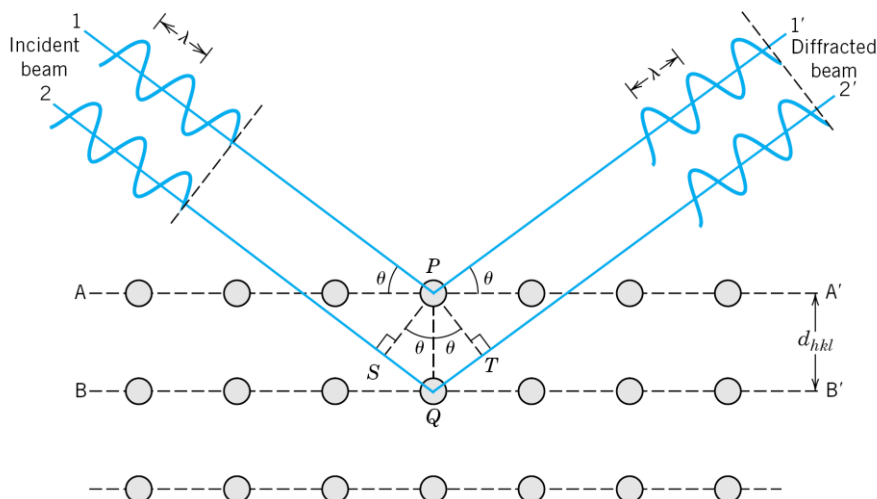
(B) Discuss the X-ray diffraction by a crystal lattice then deduce Bragg's law when X-rays are incident at an angle (θ) on a set of crystallographic planes with interplaner spacing of (d)?

(20 marks)

Answer:



Let us now examine the necessary conditions for diffraction of X-rays by a periodic arrangement of atoms.



Consider the two parallel planes of atoms A-A' and B-B' in Figure (2), which have the same h , k , and l Miller indices and are separated by the interplaner spacing d_{hkl} . Constructive interference of the scattered rays 1' and 2' occurs also at an angle θ to the planes, if the path length difference between 1-P-1' and 2-Q-2' (i.e., $SQ + QT$) is equal to a whole number, n , of wavelengths. That is, the condition for diffraction is:

$$n\lambda = SQ + QT$$

$$n\lambda = d_{hkl} \sin \theta + d_{hkl} \sin \theta$$

$$= 2 d_{hkl} \sin \theta \quad \dots(1)$$

Equation (1) is known as **Bragg's law**; also, n is the order of reflection, which may be any integer (1, 2, 3, . . .) consistent with $\sin \theta$ not exceeding unity.

- (C)** For BCC iron, the lattice parameter is 2.866 Å. Diffraction from (220) set of planes is obtained using monochromatic radiation having a wavelength of 0.1790 nm, and the order of reflection is 1. Compute: **(i)** The interplanar spacing for the (220) set of planes?
(ii) The diffraction angle? **(15 marks)**

Answer:

i) The value of the interplanar spacing d_{hkl} is determined as,

With, $a = 0.2866 \text{ nm}$,

And, $h = 2, k = 2,$ and $l = 0,$

Since we are considering the (220) planes. Therefore,

$$d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

$$= \frac{0.2866 \text{ nm}}{\sqrt{(2)^2 + (2)^2 + (0)^2}} = 0.1013 \text{ nm} (1.013 \text{ \AA})$$

(ii) The value of θ may now be computed using Equation (1), with $n = 1$, since this is a first-order reflection:

$$\sin \theta = \frac{n\lambda}{2d_{hkl}} = \frac{(1)(0.1790 \text{ nm})}{(2)(0.1013 \text{ nm})} = 0.884$$

$$\theta = \sin^{-1}(0.884) = 62.13^\circ$$

The diffraction angle is 2θ , or $2\theta = (2)(62.13^\circ) = 124.26^\circ$

Question (4) (50 marks)

(A) "A perfect crystal, with every atom of the same type in the correct position, does not exist."

Is this true? If so, what are the main types of point defects that can disturb the crystal structure in solid materials? **(20 marks)**

Answer: See the Text Book Pages 66-68

(B) Explain the linear defects within a crystal lattice and discuss using schematic diagrams the different types of these defects? **(15 marks)**

Answer: See the Text Book Pages 71 and 75

(C) For certain metal, the photoelectric effect begins at 1.1×10^{15} Hz. Find:

(i) The work function of the metal?

(ii) The maximum velocity of the electrons ejected from the metal for incident light with wavelength of 200 nm?

$$(h = 6.6 \times 10^{-34} \text{ J.s} , c = 3 \times 10^8 \text{ m/s} , m = 9.1 \times 10^{-31} \text{ Kg})$$

(15 marks)

Answer: $\lambda_0 = 275 \times 10^{-9} \text{ m}$

(i) $W = hc / \lambda_0$

$$= 6.6 \times 10^{-34} \times 3 \times 10^8 / 275 \times 10^{-9} = 7.2 \times 10^{-19} \text{ J}$$

(ii) $hc / \lambda = hc / \lambda_0 + \frac{1}{2} mv^2$

$$6.6 \times 10^{-34} \times 3 \times 10^8 / 200 \times 10^{-9} = 6.6 \times 10^{-34} \times 3 \times 10^8 / 275 \times 10^{-9} + \frac{1}{2} 9.1 \times 10^{-31} v^2$$

Then, $v = 7.7 \times 10^5 \text{ m/s}$

GOOD LUCK

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