PHYSICS PART

Question (1)   (15 degrees)

(A) Define the concepts of Amorphous and crystalline states and discuss the difference between Amorphous and crystalline solids?

> **Answer:**

- **Amorphous Solids:** which do not possess long-range order or no order of atoms positions.

  Crystalline Solids: which are characterized by atoms arranged in a regular pattern, extending in the three dimensions.

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) Use the band structure of materials to explain how can materials be classified into conductors, semiconductors and insulators? (your answer must be supported by the energy band diagrams)

Answer:

5.1. 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.


Insulator
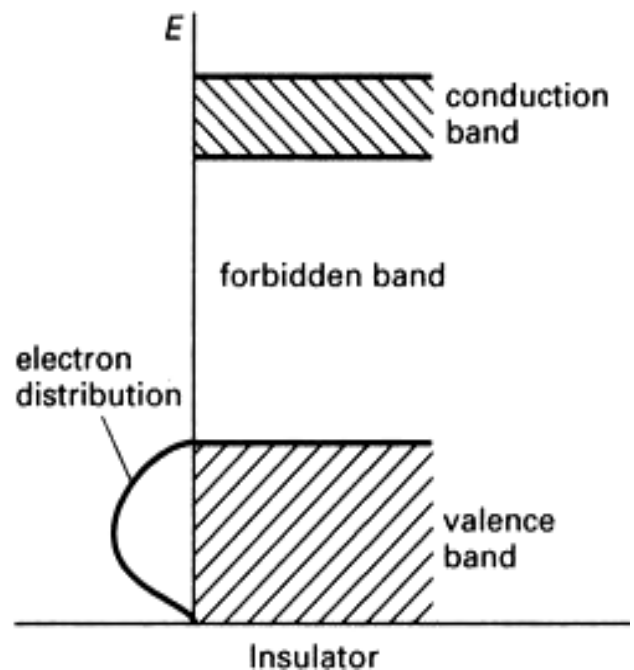
Conductors

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
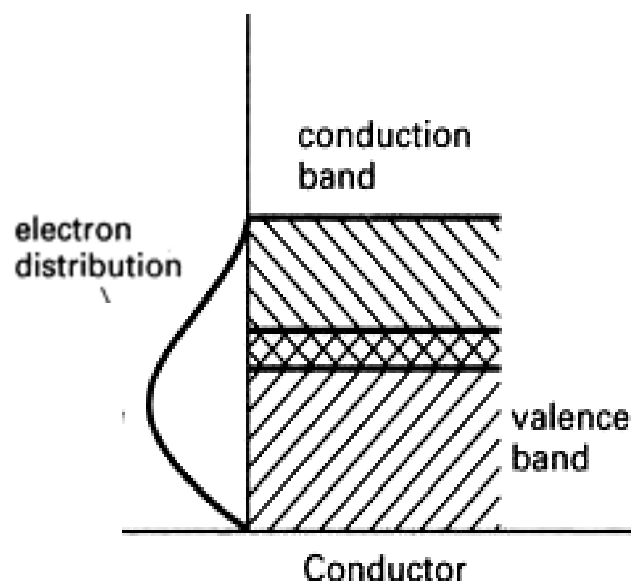
Conductor

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.
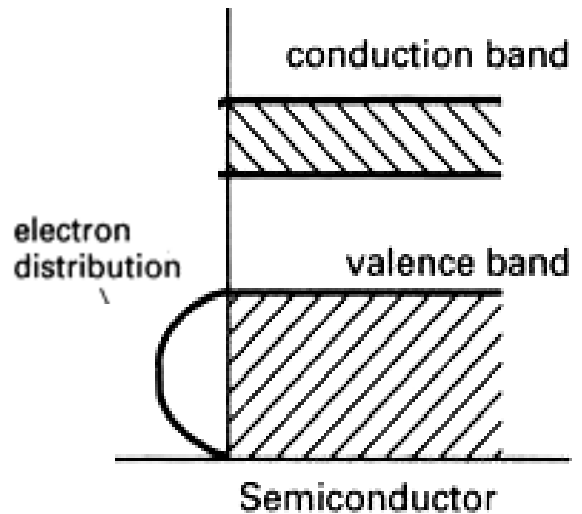
(C) An unknown metal is found to have lattice parameters as: $a = b = c$ and, $\alpha = \beta = \gamma = 90^\circ$ Based on this information,

            i) Determine the type of this crystal system?

            ii) What are the types of Bravias lattices due to this system?

Answer:

       i) It is Cubic crystal system

       ii) There are three Bravais lattices for this system: Simple Cubic (SC), Body Centered Cubic (BCC) and Face Centered Cubic (FCC)

(D) Sodium has atomic mass of 22.99 g/mol and 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 $= 6 \times 10^{23}$ atom/mole]

Answer:

n = 2

$\rho = 0.971$ g/cm³

A = 22.99 g/mol

Avogadro's number $= 6 \times 10^{23}$ atom/mole

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

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

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

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

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

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

Question (2)   (15 degrees)

(A) Give short notes on:

i) Covalent-bonded materials.

Where a compound only contains nonmetal atoms, a covalent bond is formed by atoms sharing two or more electrons. Nonmetals have 4 or more electrons in their outer shells (except boron). With this many electrons in the outer shell, it would require more energy to remove the electrons than would be gained by making new bonds. Therefore, both the atoms involved share a pair of electrons. Each atom gives one of its outer electrons to the electron pair, which then spends some time with each atom. Consequently, both atoms are held near each other since both atoms have a share in the electrons.
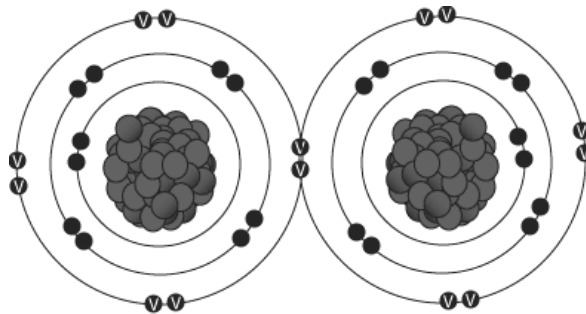

In *solid materials with covalent bonds*, the binding energies are of ~ 10 eV per molecule and hence covalent bonds are very strong. Generally, solid materials with covalent bonds:

- 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.

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ii) Bragg's law for diffraction.

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Let us now examine the necessary conditions for diffraction of X-rays by a periodic arrangement of atoms.
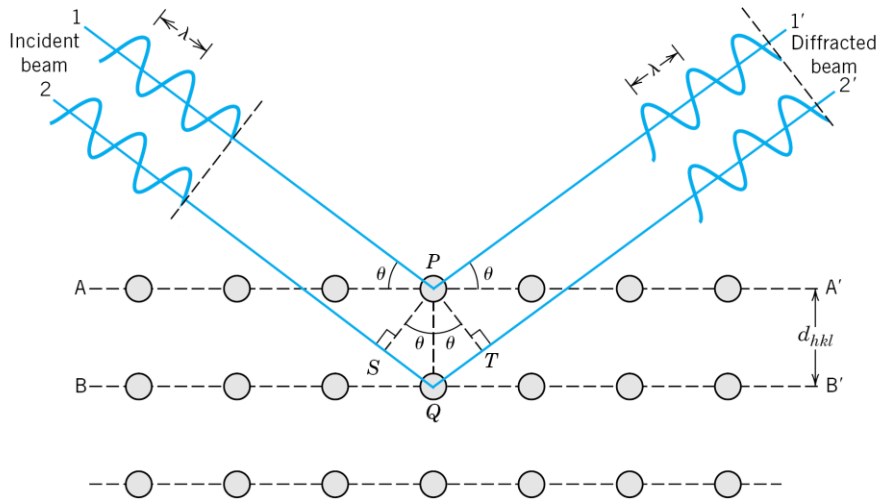
Consider the two parallel planes of atoms A–A' and B–B' in Figure (2), which have the same h, k, and l Miller indices and are separated by the interplanar spacing d_{hkl}. Constructive interference of the scattered rays 1' and 2' occurs also at an angle θ to the planes, if the path length difference 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:

$$n \lambda = SQ + QT$$

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

$$= 2 \ d_{hkl} \sin \theta \qquad .....(1)$$

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 θ not exceeding unity.

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iii) Types of doped semiconductors.

## a. n-type semiconductors

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In this case, a very small number of atoms of group V elements such as arsenic (As) are added to the silicon (Si) crystal as substitutional atoms in the lattice. Arsenic atoms have five valence electrons while silicon atoms has only four valence electrons so, the fifth electrons of arsenic are bound only weakly to their parent impurity atoms (the bonding energies are of the
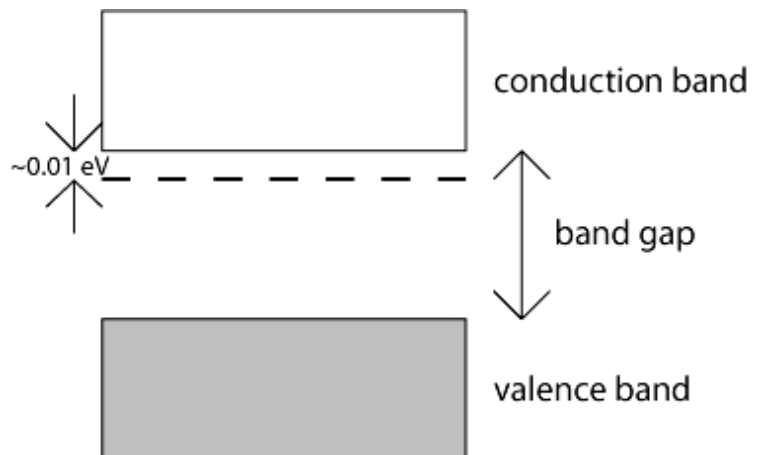
order of 0.01 eV), This is often represented schematically in band diagrams by the addition of 'donor levels' just below the bottom of the conduction band.

b. p-type semiconductors

In this case, a very small number of atoms of group III elements such as gallium (Ga) are added to the silicon (Si) crystal as substitutional atoms in the lattice. Gallium atoms have three valence electrons while silicon (Si) atoms has only four valence electrons so, this case results in presence of vacancies called holes in the electron structure of the crystal. This is often represented schematically in band diagrams by the addition of 'acceptor levels' just above the highest valence band
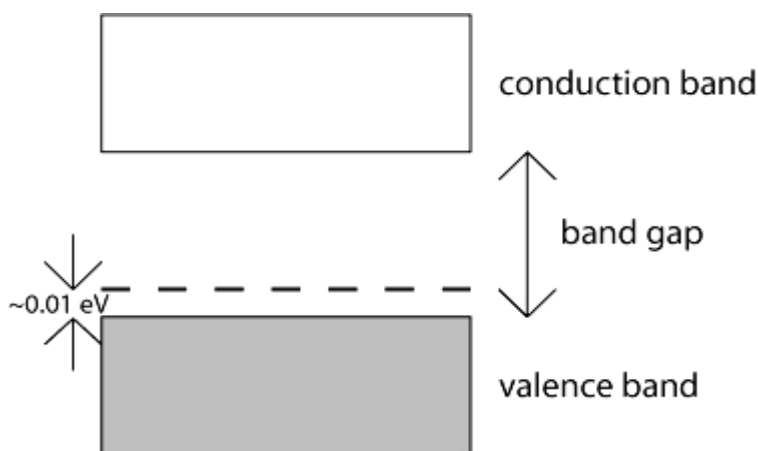
(B) Discuss the concept of absorption spectroscopy then define what is meant by electronic, vibrational, rotational lines?

Absorption spectroscopy refers to spectroscopic techniques that measure the absorption of radiation, as a function of frequency or wavelength, due to its interaction with a sample. The sample absorbs energy, i.e., photons, from the radiating field. The intensity of the absorption varies as a function of frequency, and this variation is the absorption spectrum. Absorption spectroscopy is performed across the electromagnetic spectrum.
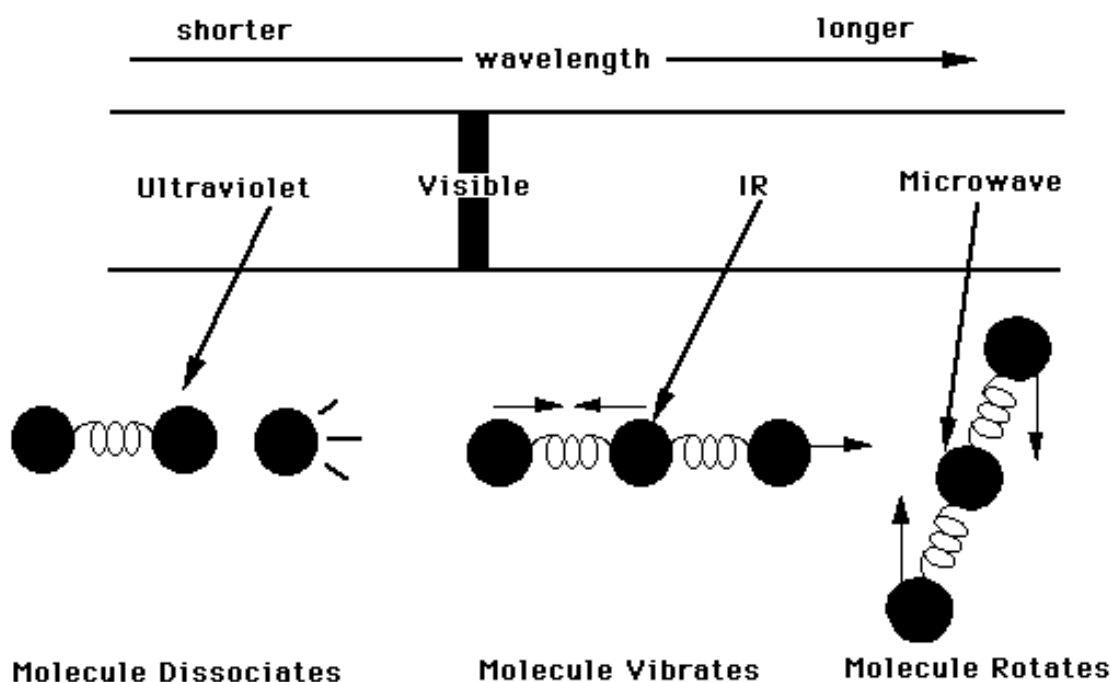
Absorption lines are typically classified by the nature of the quantum mechanical change induced in the molecule or atom. *Rotational lines,* for instance, occur when the

rotational state of a molecule is changed. Rotational lines are typically found in the microwave spectral region. **Vibrational lines,** correspond to changes in the vibrational state of the molecule and are typically found in the infrared region. **Electronic lines,** correspond to a change in the electronic state of an atom or molecule and are typically found in the visible and ultraviolet region.

(C) For BCC iron, the lattice parameter is 2.866 A°. 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?

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

　　With,　$a = 0.2866$ nm,

　　And,　$h = 2, k = 2,$ and $l = 0$,

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

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

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

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

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

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

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

(D) Find the velocity of the electrons that are ejected from a metal surface which was illuminated by a green light of 550 nm? The electron emission from the metal begins at 1×10^{14} Hz.

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

　　Answer: $\lambda = 550 \times 10^{-9}$ m　,　$v_o = 1 \times 10^{14}$ Hz　,　$v = ?$

　　　　$h c / \lambda$　$=$　$h v_o$　$+$　$\frac{1}{2} m v^2$

$(6.6 \times 10^{-34}) (3 \times 10^8) / (550 \times 10^{-9}) = (6.6 \times 10^{-34}) (1 \times 10^{14}) + \frac{1}{2} (9.1 \times 10^{-31}) v^2$

　　　　Then,　$v = 8 \times 10^5$ m/s