CH 222 Chapter Ten Concept Guide

1. Types of Intermolecular Forces

Question

What type if intermolecular force is involved in each case below? Place the following cases in order of decreasing strength of interaction.

(a) Liquid methane, CH_4
(b) Mixture of water and methanol, H_2O and CH_3OH
(c) Solution of LiCl in water

Solution

(a) No ions are involved with CH_4. It is a simple molecule with covalent bonds. It is also nonpolar, thus the only way methane molecules can interact is through induced dipole forces.

(b) Similarly to CH_4, there are no ions involved with these covalently bonded molecules. H_2O and CH_3OH are, however, polar and both have an O-H bond. They interact, therefore, through special dipole-dipole forces: hydrogen bonding.

(c) LiCl is an ionic compound composed of Li^+ and Cl^- ions and water is a polar molecule. In this case, the salt dissociates in water and the ions interact with water molecules through ion-dipole forces.

In order of decreasing strength, the interactions are:

LiCl in H_2O H_2O in CH_3OH liquid CH_4.

2. Types of Intermolecular Forces

Question

What type of intermolecular forces is involved in each case below? Place the following cases in order of decreasing strength of interaction.

(a) liquid O_2
(b) $MgSO_4$ dissolved in water
(c) O_2 dissolved in H_2O

Solution

(a) O_2 interactions occur by induced dipole-induced dipole forces. These are the weakest of all forces.

(b) $MgSO_4$ dissociates into Mg^{2+} and SO_4^{2-} ions when dissolved in water. The ions interact with water through ion-dipole forces.

(c) Water is a polar molecular compound. O_2 is composed of nonpolar molecules. Dipole-induced dipole forces exist between H_2O and O_2.

In order of decreasing strength, the interactions are:

$MgSO_4$ dissolved in H_2O O_2 dissolved in H_2O liquid O_2.

3. Explaining Differences in Boiling Points

Problem

Explain why the boiling point of H_2S is lower than that of H_2O.

Solution

There is significant hydrogen bonding between the molecules in H_2O, but not in H_2S. This difference arises because oxygen's electronegativity is much greater than sulfur's electronegativity. Hydrogen bonding increases a substance's boiling point, thus H_2O has a higher boiling point than H_2S. Recall from this lesson that the difference between the boiling points of ethanol and dimethyl ether is also due to differences in the strength of forces, and more specifically, the lack of hydrogen bonding in dimethyl ether.

4. Characteristics of Liquids

Question

Why do gases completely fill their containers and liquids spread to take the shape of their containers?

Answer

Gases and liquids flow simply due to the movement of molecules. In comparison, a solid has too rigid a structure to allow for flow. Its molecules cannot move past one another.

5. Characteristics of Liquids

Question

What factors determine the viscosity of a liquid? How does viscosity change with a decrease in temperature?

Answer

The size, shape, and chemical nature of molecules, as well as a sample's temperature, determine the viscosity of a liquid. As temperature decreases, viscosity increases due to less rapid movement of the molecules and a lessened ability to overcome intermolecular forces in order to move past one another.

6. Normal Boiling Point

Question

The normal boiling point of CH_3Cl, chloromethane, is -24 °C and the normal boiling point for CH_3I is 42.4 °C. Which compound has the stronger intermolecular forces in the liquid phase? What types of intermolecular forces are involved?

Answer

The forces involved are dipole-dipole attractions and dispersion (induced dipole) forces. CH_3Cl has a larger dipole (1.892 D) than CH_3I, therefore one might expect CH_3Cl to have stronger intermolecular forces as a liquid. However, the larger iodine atom in CH_3I is more polarizable, yielding greater induced dipole attractive forces than the chlorine atom in CH_3Cl, giving CH_3I a higher normal boiling point.

7. Vapor Pressure: Water

Question

Why does water boil at a lower temperature at the top of a mountain than it does at sea level?

Answer

External atmospheric pressure decreases with increasing altitude. When water is heated on a mountaintop, its vapor pressure reaches this lower atmospheric pressure at a lower temperature. The water boils sooner, yet it will take longer to cook food in this water because the boiling point is lower.

8. Lattice Energy

Question

Lattice energy is defined as the net force of attraction between ions in an extended solid. It is the energy released if one mole of gas phase ions would come together to form the solid lattice. Write a chemical equation illustrating the reaction between M^{2+} and X^{2-} that fits this definition. How does the value of the lattice energy change as ionic charge decreases and as ionic radius decreases?

Answer

The energy liberated as gaseous ions combine to give a crystalline ionic structure may be illustrated as:

$$M^{2+} (g) + X^{2-} (g) \rightarrow MX (s)$$

The lattice energy depends on Coulomb's Law. Therefore, lattice energy decreases with decreasing ionic charge and increases with decreasing ionic radius.

9. Lattice Energy

Question

Which compound should have the higher lattice energy: $CaCl_2$ or $BaCl_2$?

Answer

Lattice energy depends inversely on the size of the ions involved: the smaller the ions, the stronger the electrostatic attraction between them, and the larger the lattice energy. Here, Ca^{2+} is smaller than Ba^{2+}, thus $CaCl_2$ is anticipated to have the higher lattice energy.

10. Summary of Cubic Unit Cells

Question

How many net atoms or ions does a (a) simple cubic unit cell, (b) body-centered cubic unit cell, and (c) face-centered cubic unit cell have?

Answer

(a) A simple cubic unit cell has 8 atoms in corner positions, and one eighth of each is contained in each unit cell. So, a simple cubic unit cell of atoms or ions always contains 1 net atom or ion.

(b) A body-centered cubic unit cell is similar to a simple cubic unit cell, but also contains an atom or ion at its center. Therefore, a body-centered cubic unit cell of atoms always contains 2 net atoms within the cell.

(c) A face-centered cubic unit cell of X atoms or ions always contains 4 net atoms or ions within the cell.

11. Unit Cell - Volume and Density

Question

The unit cell length of diamond was measured as 0.3567 nm.

(a) What is the volume of this cubic unit cell in cubic centimeters?

(b) If the mass of unit cell of a diamond is 1.60×10^{-22} g, what is the theoretical density of diamond?

Approach

The volume of the cubic unit is found by cubing the length of the side. Density can be calculated by dividing the mass of diamond by the volume.

Solution

(a) Conversion factors are needed to express the unit cell length in centimeters. Cubing this number gives the volume of the cubic unit.

$$(0.3567 \text{ nm})\left(\frac{1 \text{ m}}{10^9 \text{ nm}}\right)\left(\frac{100 \text{ cm}}{1 \text{ m}}\right) = 3.567 \times 10^{-8} \text{ cm}$$

Volume = $(3.567 \times 10^{-8})^3 = 4.538 \times 10^{-23}$ cm^3

(b) To calculate the theoretical density of diamond having a mass of 1.60×10^{-22} g, divide the mass of the unit cell by its volume.

$$\frac{1.60 \times 10^{-22} \text{ g}}{4.538 \times 10^{-23} \text{ cm}^3} = 3.50 \text{ g/cm}^3$$

12. Structures and Formulas of Ionic Solids

Question

Can calcium chloride have a unit cell like that of sodium chloride?

Solution

A unit cell of NaCl can only have a 1:1 cation to anion ration. $CaCl_2$ has a 1:2 cation to anion ratio, therefore it cannot have a unit cell like NaCl.

13. Determination of an Atomic Radius from Measurements of a Crystal Lattice: Aluminum

Problem

Aluminum has a density of 2.70 g/cm^3 and the atoms are packed into a face-centered cubic unit cell. Calculate the radius of an aluminum atom.

Approach

First, calculate the mass of a unit cell with the knowledge that it is face-centered cubic, and thus has 4 atoms per unit cell. Second, combine the density of aluminum with the mass of the unit cell to calculate the volume of the unit cell. The volume may then be used to find the length of an edge of the unit cell. Last, calculate the radius of an aluminum atom from the edge dimension.

Solution

Step 1. The mass of the unit cell is

$$\left(26.98\ \text{g / mol Al}\right)\left(\frac{1\ \text{mol}}{6.022\times 10^{+23}\ \text{atoms}}\right)\left(4\ \text{atoms / unit cell}\right) = 1.792\times 10^{-22}\ \text{g / unit cell}$$

Step 2. Calculate the volume of the unit cell by dividing the mass of the unit cell by the density of aluminum.

$$\left(1.792\times 10^{-22}\ \text{g / unit cell}\right)\left(\frac{1\ \text{cm}^3}{2.70\ \text{g}}\right) = 6.64\times 10^{-23}\ \text{cm}^3\text{ / unit cell}$$

Step 3. To find the length of a unit cell edge, calculate the cube root of the cube volume.

$$\sqrt[3]{6.64\times 10^{-23}}\ \text{cm}^3\text{ / unit cell} = 4.05\times 10^{-8}\ \text{cm}$$

Step 4. The diagonal distance across a face-centered cubic unit cell is

$$\text{Diagonal distance}^2 = (\text{edge})^2 + (\text{edge})^2 = 2\ (\text{edge})^2$$

Taking the square root of both sides yields:

$$\text{diagonal distance} = \left(\sqrt{2}\right)\left(\text{cell edge}\right)$$

Plugging in the cell edge:

$$\text{diagonal distance} = \left(\sqrt{2}\right)\left(4.05 \times 10^{-8}\ \text{cm}\right) = 5.73 \times 10^{-8}\ \text{cm}$$

To find the atomic radius of aluminum, divide the diagonal distance by 4.

$$\frac{5.73 \times 10^{-8}\ \text{cm}}{4} = 1.43 \times 10^{-8}\ \text{cm}$$

The atomic radius for aluminum is 1.43×10^{-8} cm or 143 pm.

14. Critical Points

Question

What is the critical point? Will a substance always be a liquid below the critical point?

Answer

The critical point is the temperature above which no amount of pressure will cause condensation (movement of molecules from the gas phase to the liquid phase). No, a substance will not always be a liquid below the critical point. All solids, for example, are below the critical point and many gases exist below their critical point.

15. Triple Points

Question

How many phases can co-exist at equilibrium at a triple point? Refer to the phase diagram for water in this lesson.

Answer

There are three phases at a triple point: solid, liquid, and gas.

16. Phase Changes: CO_2

Question

Refer to a phase diagram for CO_2. If a sample of CO_2 is at its triple point, what phase is present after the pressure has been increased at constant temperature?

Answer

After increasing pressure, CO_2 will be in its solid form. The solid form is favored over the liquid at high pressure because $CO_2(s)$ is more dense than $CO_2(\ell)$.