CHAPTER SEVEN
Intermolecular Forces

7.51 a. Sulfur dioxide and carbon monoxide have permanent dipoles and exhibit dipole-dipole interactions.
b. H_2O and Cl_2 attract each other through a dipole-induced dipole interaction.
c. The solvation of Cl^- by water is an example of ion-dipole interactions.
d. Octane (C_8H_{18}) or nitrogen are examples of dispersion interactions.
e. All of the above fall under the category of Van der Waals interactions. Another example is CO_2

7.52 Polarizability refers to the ease with which the electron distribution in the atom (or molecule) can be distorted. Generally, the larger the number of electrons and the more diffuse the electron cloud in the atom or molecule, the greater its polarizability. Polarizability is related to intermolecular forces in that the polarizability affects the likelihood of a dipole moment being induced.

7.53 A temporary dipole moment exists only transiently and fluctuates over time. A permanent dipole moment exists at all times and does not fluctuate.

7.54 All atoms and molecules can be condensed in either liquid or solid form at a low enough temperature. This indicates that in all substances there is some form of attractive force that holds the liquid or solid phases together.

7.55 Compounds with stronger intermolecular forces will have higher melting and boiling points. A high melting and boiling point indicates it takes a high amount of energy to separate molecules from each other.

7.56 The elements that can take part in hydrogen bonding or Nitrogen, Oxygen, & Fluorine. Hydrogen is unique in this kind of interaction in that the average energy of hydrogen bond is quite large for a dipole-dipole interaction. Thus, hydrogen bonds have a powerful effect on the structures and properties of many compounds.

7.57 ICl has a dipole moment and Br_2 does not. The dipole moment increases the intermolecular attractions between ICl molecules and causes that substance to have a higher melting point than bromine.

7.58 The three molecules are essentially nonpolar. There is little difference in electronegativity between carbon and hydrogen. Thus, the only type of intermolecular attraction in these molecules is dispersion forces. Other factors being equal, the molecule with the greater number of electrons will exert greater intermolecular attractions. By looking at the molecular formulas you can predict that the order of increasing boiling points will be $CH_4 < C_3H_8 < C_4H_{10}$.

On a very cold day, propane and butane would be liquids (boiling points $-44.5°C$ and $-0.5°C$, respectively); only methane would still be a gas (boiling point $-161.6°C$).

7.59 All are tetrahedral (AB_4 type) and are nonpolar. Therefore, the only intermolecular forces possible are dispersion forces. Without worrying about what causes dispersion forces, you only need to know that the strength of the dispersion force increases with the number of electrons in the molecule (all other things being equal). As a consequence, the magnitude of the intermolecular attractions and of the boiling points should increase with increasing molar mass.

7.60 **(a)** Benzene (C_6H_6) molecules are nonpolar. Only dispersion forces will be present.

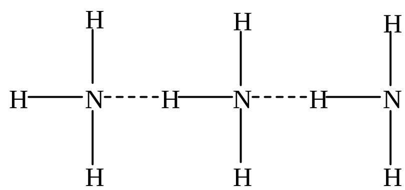
(b) Chloroform (CH_3Cl) molecules are polar (why?). Dispersion and dipole-dipole forces will be present.

(c) Phosphorus trifluoride (PF_3) molecules are polar. Dispersion and dipole-dipole forces will be present.

(d) Sodium chloride (NaCl) is an ionic compound. Ion-ion (and dispersion) forces will be present.

(e) Carbon disulfide (CS_2) molecules are nonpolar. Only dispersion forces will be present.

7.61 The center ammonia molecule is hydrogen–bonded to two other ammonia molecules.



7.62 In this problem you must identify the species capable of hydrogen bonding among themselves, not with water. In order for a molecule to be capable of hydrogen bonding with another molecule like itself, it must have at least one hydrogen atom bonded to N, O, or F. Of the choices, only (e) CH_3COOH (acetic acid) shows this structural feature. The others cannot form hydrogen bonds among themselves.

7.63 CO_2 is a nonpolar molecular compound. The only intermolecular force present is a relatively weak dispersion force (small molar mass). CO_2 will have the lowest boiling point.

CH_3Br is a polar molecule. Dispersion forces (present in all matter) and dipole–dipole forces will be present. This compound has the next highest boiling point.

CH_3OH is polar and can form hydrogen bonds, which are especially strong dipole-dipole attractions. Dispersion forces and hydrogen bonding are present to give this substance the next highest boiling point.

RbF is an ionic compound (Why?). Ion–ion attractions are much stronger than any intermolecular force. RbF has the highest boiling point.

7.64 1-butanol has the higher boiling point because the molecules can form hydrogen bonds with each other. Diethyl ether molecules do contain both oxygen atoms and hydrogen atoms. However, all the hydrogen atoms are bonded to carbon, not oxygen. There is no hydrogen bonding in diethyl ether, because carbon is not electronegative enough.

7.65 **(a)** Cl_2: it has more electrons the O_2 (both are nonpolar) and therefore has stronger dispersion forces.

(b) SO_2: it is polar (most important) and also has more electrons than CO_2 (nonpolar). More electrons imply stronger dispersion forces.

(c) HF: although HI has more electrons and should therefore exert stronger dispersion forces, HF is capable of hydrogen bonding and HI is not. Hydrogen bonding is the stronger attractive force.

7.66 **(a)** Xe: it has more electrons and therefore stronger dispersion forces.

(b) CS_2: it has more electrons (both molecules nonpolar) and therefore stronger dispersion forces.

(c) Cl_2: it has more electrons (both molecules nonpolar) and therefore stronger dispersion forces.

(d) LiF: it is an ionic compound, and the ion-ion attractions are much stronger than the dispersion forces between F_2 molecules.

(e) NH_3: it can form hydrogen bonds and PH_3 cannot.

7.67 **(a)** CH_4 has a lower boiling point because NH_3 is polar and can form hydrogen bonds; CH_4 is nonpolar and can only form weak attractions through dispersion forces.

(b) KCl is an ionic compound. Ion–Ion forces are much stronger than any intermolecular forces. I_2 is a nonpolar molecular substance; only weak dispersion forces are possible.

7.68 **(a)** Water has O–H bonds. Therefore, water molecules can form hydrogen bonds. The attractive forces that must be overcome are hydrogen bonding and dispersion forces.

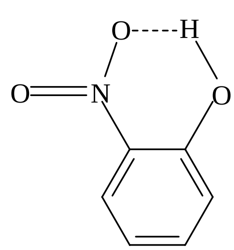
(b) Bromine (Br_2) molecules are nonpolar. Only dispersion forces must be overcome.

(c) Iodine (I_2) molecules are nonpolar. Only dispersion forces must be overcome.

(d) In this case, the F–F bond must be broken. This is an *intra*molecular force between two F atoms, not an *inter*molecular force between F_2 molecules. The attractive forces of the covalent bond must be overcome.

7.69 The linear structure (*n*–butane) has a higher boiling point (−0.5°C) than the branched structure (2–methylpropane, boiling point −11.7°C) because the linear form can be stacked together more easily.

7.70 The lower melting compound (shown below) can form hydrogen bonds only with itself (*intra*molecular hydrogen bonds), as shown in the figure. Such bonds do not contribute to *inter*molecular attraction and do not help raise the melting point of the compound. The other compound can form *inter*molecular hydrogen bonds; therefore, it will take a higher temperature to provide molecules of the liquid with enough kinetic energy to overcome these attractive forces to escape into the gas phase.



7.71 **(a)** Boiling liquid ammonia requires breaking hydrogen bonds between molecules. Dipole–dipole and dispersion forces must also be overcome.

(b) P_4 is a nonpolar molecule, so the only intermolecular forces are of the dispersion type.

(c) CsI is an ionic solid. To dissolve in any solvent ion–ion interparticle forces must be overcome.

(d) Metallic bonds must be broken.

7.72 **(a)** A low surface tension means the attraction between molecules making up the surface is weak. Water has a high surface tension; water bugs could not "walk" on the surface of a liquid with a low surface tension.

(b) A low critical temperature means a gas is very difficult to liquefy by cooling. This is the result of weak intermolecular attractions. Helium has the lowest known critical temperature (5.3 K).

(c) A low boiling point means weak intermolecular attractions. It takes little energy to separate the particles. All ionic compounds have extremely high boiling points.

(d) A low vapor pressure means it is difficult to remove molecules from the liquid phase because of high intermolecular attractions. Substances with low vapor pressures have high boiling points (why?).

Thus, only choice (d) indicates strong intermolecular forces in a liquid. The other choices indicate weak intermolecular forces in a liquid.

7.73 The HF molecules are held together by strong intermolecular hydrogen bonds. Therefore, liquid HF has a lower vapor pressure than liquid HI. (The HI molecules do not form hydrogen bonds with each other.)

7.74 **(a)** **False**. Permanent dipoles are usually much stronger than temporary dipoles.

(b) **False**. The hydrogen atom must be bonded to N, O, or F.

(c) **True**.

(d) **False**. The magnitude of the attraction depends on both the ion charge and the polarizability of the neutral atom or molecule.

7.75 **(a)** K_2S: Ionic forces are much stronger than the dipole-dipole forces in $(CH_3)_3N$.

(b) Br_2: Both molecules are nonpolar; but Br_2 has more electrons. (The boiling point of Br_2 is 50°C and that of C_4H_{10} is −0.5°C.)

7.76 CH_4 is a tetrahedral, nonpolar molecule that can only exert weak dispersion type attractive forces. SO_2 is bent (why?) and possesses a dipole moment, which gives rise to stronger dipole-dipole attractions. Sulfur dioxide will have a larger value of “a” in the van der Waals equation (a is a measure of the strength of the interparticle attraction) and will behave less like an ideal gas than methane.

7.77 LiF, ionic bonding and dispersion forces; BeF_2, ionic bonding and dispersion forces; BF_3, dispersion forces; CF_4, dispersion forces; NF_3, dipole-dipole interaction and dispersion forces; OF_2, dipole-dipole interaction and dispersion forces; F_2, dispersion forces.

7.78 **(a)** If water were linear, the two O−H bond dipoles would cancel each other as in CO_2. Thus a linear water molecule would not be polar.

(b) Hydrogen bonding would still occur between water molecules even if they were linear.

7.79 The cane is made of many molecules held together by intermolecular forces. The forces are strong and the molecules are packed tightly. Thus, when the handle is raised, all the molecules are raised because they are held together.