

## Section 4.7: Intermolecular Forces

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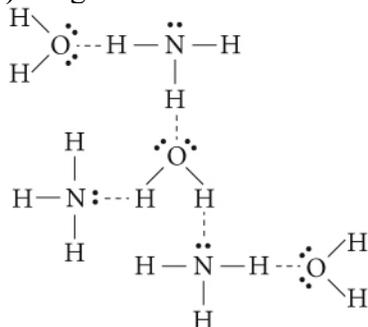
1. Of  $\text{CH}_3\text{OH}$ ,  $\text{CH}_3\text{CH}_2\text{OH}$ , and  $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$ ,  $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$  has the highest boiling point. All three molecules will experience dipole–dipole interactions, because of their hydrogen bonds, which provide an attractive force in a liquid. But  $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$  has the highest molecular mass, so it will have the greatest London dispersion forces and thus the highest boiling point.
2. Of  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_2$  and  $\text{Cl}_2$ ,  $\text{Cl}_2$  will have the lower boiling point because  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_2$  has dipole–dipole forces whereas  $\text{Cl}_2$  has only London dispersion forces, which is a weaker force.

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1. (a) HBr has the highest boiling point of HBr, Kr, and  $\text{Cl}_2$ . HBr has dipole–dipole forces between its molecules as well as London dispersion forces while the other substances have only London dispersion forces.  
(b) NaCl has the highest freezing point of  $\text{H}_2\text{O}$ , NaCl, and HBr because NaCl is an ionic compound. The ionic bond in NaCl is a stronger attractive force than any of the intermolecular forces in the other molecules.  
(c) Of  $\text{Cl}_2$ ,  $\text{Br}_2$ , and  $\text{I}_2$ ,  $\text{I}_2$  has the lowest vapour pressure at  $25^\circ\text{C}$ .  $\text{I}_2$  is the largest molecule and will have the strongest London dispersion forces, which prevent the substance from changing into vapour.  
(d)  $\text{N}_2$  has the lowest freezing point of  $\text{N}_2$ , CO, and  $\text{CO}_2$ .  $\text{N}_2$  has the weakest interactions because it is the smallest molecule and exerts only London dispersion forces.  
(e)  $\text{CH}_4$  has the lowest boiling point of  $\text{CH}_4$ ,  $\text{CH}_3\text{CH}_3$ , and  $\text{CH}_3\text{CH}_2\text{CH}_3$ .  $\text{CH}_4$  is the smallest molecule of all and will have the weakest London dispersion forces.  
(f) HF has the highest boiling point of HF, HCl, and HBr. HF will have the strongest dipole–dipole forces due to hydrogen bonding.
2. (a)  $\text{CBr}_4$  has the highest boiling point of  $\text{CCl}_4$ ,  $\text{CF}_4$ , and  $\text{CBr}_4$ .  $\text{CBr}_4$  is the largest molecule and will have the strongest London dispersion forces.  
(b)  $\text{F}_2$  has the lowest freezing point of LiF,  $\text{F}_2$ , and HCl.  $\text{F}_2$  has the weakest intermolecular forces because it has only London dispersion forces.  
(c) Of  $\text{CH}_3\text{OCH}_3$ ,  $\text{CH}_3\text{CH}_2\text{OH}$ , and  $\text{CH}_3\text{CH}_2\text{CH}_3$ ,  $\text{CH}_3\text{CH}_2\text{OH}$  has the lowest vapour pressure at  $25^\circ\text{C}$ .  $\text{CH}_3\text{CH}_2\text{OH}$  has the strongest intermolecular forces because it has the strongest dipole–dipole forces due to hydrogen bonding.  
(d)  $\text{H}_2\text{O}_2$  has the greatest viscosity of HF and  $\text{H}_2\text{O}_2$ .  $\text{H}_2\text{O}_2$  has more hydrogen bonding than HF does because it can form hydrogen bonds at both ends of the molecule.  
(e)  $\text{H}_2\text{CO}$  has the greatest heat of vaporization of  $\text{H}_2\text{CO}$ ,  $\text{CH}_3\text{CH}_3$ , and  $\text{CH}_4$ .  $\text{H}_2\text{CO}$  has the strongest intermolecular forces because of its dipole–dipole interactions.

3. (a) Ammonia has a very high solubility in water because it is a polar molecule and has hydrogen bonding.

(b) Diagram of water interacting with ammonia molecules:



4. (a) OCS has stronger intermolecular forces than CO<sub>2</sub>, since in OCS there is a net dipole in the direction of the O, creating dipole–dipole forces between molecules, whereas CO<sub>2</sub> will only have London dispersion forces.

(b) SeO<sub>2</sub> has stronger intermolecular forces than SO<sub>2</sub>. Both SO<sub>2</sub> and SeO<sub>2</sub> have dipoles due to the bent shape of the molecules, but the bonds between oxygen and selenium are more polar than the bonds of SO<sub>2</sub> because selenium is less electronegative than sulfur is. Since SeO<sub>2</sub> has a stronger dipole, its dipole–dipole interactions are stronger. Also, Se is a larger molecule than S and will create larger London dispersion forces between molecules.

(c) H<sub>2</sub>NCH<sub>2</sub>CH<sub>2</sub>NH<sub>2</sub> has stronger intermolecular forces than CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>NH<sub>2</sub>.

H<sub>2</sub>NCH<sub>2</sub>CH<sub>2</sub>NH<sub>2</sub> will create larger dipole–dipole forces between molecules due to the presence of an additional nitrogen atom (more opportunities for hydrogen bonding).

(d) H<sub>2</sub>CO has stronger intermolecular forces than CH<sub>3</sub>CH<sub>3</sub>. H<sub>2</sub>CO has dipole–dipole forces between molecules, which are stronger than the London dispersion forces of CH<sub>3</sub>CH<sub>3</sub>.

(e) CH<sub>3</sub>OH has stronger intermolecular forces than H<sub>2</sub>CO. Both molecules have dipole–dipole forces between molecules but CH<sub>3</sub>OH can also undergo hydrogen bonding. In H<sub>2</sub>CO, the hydrogen atoms are bonded to carbon, not oxygen.

5. Of the compounds Cl<sub>2</sub>, HCl, F<sub>2</sub>, NaF, and HF, the one that has a boiling point closest to that of argon is F<sub>2</sub>. Ar has a very low boiling point, due to the very weak interatomic forces of the noble gases. NaF is an ionic compound with a high boiling point. HCl and HF have dipole–dipole forces between molecules, so they will also have high boiling points. Cl<sub>2</sub> is a larger molecule than F<sub>2</sub>, so Cl<sub>2</sub> will have larger London dispersion forces between molecules than F<sub>2</sub> does.

6. Matching boiling points and compounds:

(a) Ethanol's boiling point is 78.5 °C. Ethanol, CH<sub>3</sub>CH<sub>2</sub>OH, has the highest of the three boiling points because it has the strongest dipole–dipole forces between molecules due to hydrogen bonding.

(b) Dimethyl ether's boiling point is –23 °C. Dimethyl ether, CH<sub>3</sub>OCH<sub>3</sub>, has the second-highest boiling point because it has dipole–dipole forces between molecules.

(c) Propane's boiling point is –42.1 °C. Propane, CH<sub>3</sub>CH<sub>2</sub>CH<sub>3</sub>, has the lowest boiling point because it has only London dispersion forces between molecules.

7. (a) London dispersion forces, dipole–dipole forces, and hydrogen bonding are all present in alcohols.
- (b) London dispersion forces, dipole–dipole forces, and hydrogen bonding are all present in amines.
- (c) London dispersion forces are present in hydrocarbons.
- (d) London dispersion forces, dipole–dipole forces, and hydrogen bonding are all present in carboxylic acids.
- (e) London dispersion forces and dipole–dipole forces are present in ethers.
8. If the molecular masses of the compounds listed in Question 4 were equal, you would expect the compound with the strongest intermolecular forces to have the highest boiling point. Eliminating the compounds with no hydrogen bonding leaves  $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$ ,  $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2$ , and  $\text{CH}_3\text{OH}$ . Of these,  $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$  has the most opportunities for hydrogen bonding, so  $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$  will have the highest boiling point.