Name ________________________________**Chem 162, Section**: _______**Group Number:** ______

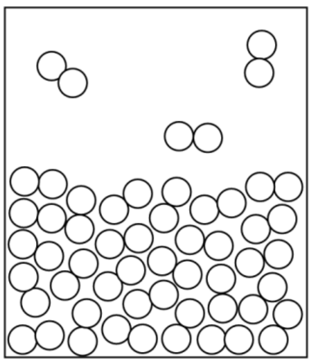
ALE 18. Intermolecular Forces of Attraction (IMF's)

(Reference: 12.3 *Silberberg 5th edition*)

How do intermolecular forces determine liquids' boiling points?

The Model: Intermolecular versus Intramolecular Forces

Within a bulk sample (*e.g.*, solid or liquid) of a molecular substance, there are discrete particles called molecules.



A liquid of diatomic bromine in equilibrium with its vapor. (In this freeze frame, the size of the molecules is greatly exaggerated!)

Breaking *intermolecular* forces:

$$Br_2(l) \rightarrow Br_2(g) \qquad \Delta H = 30.9 \text{ kJ}$$

Breaking *intramolecular* forces:

$$Br_2(g) \rightarrow 2\ Br(g) \qquad \Delta H = 192.9 \text{ kJ}$$

Key Questions

1. In the diagram of bromine above:

a. shade a pair of circles representing atoms that are covalently bound together.

b. draw a curve around a pair of molecules that are held together in the liquid phase.

2a. What is an *intra*molecular force?

b. Compare the strength of intermolecular forces with that of intramolecular forces.

3a. According to the above cartoon, when a substance vaporizes, what type of forces is broken: intermolecular or intramolecular? (Circle your choice.)

b. Are the other type of forces (*i.e.*, the one that was not the answer to Question 3a) broken? Yes or No (Circle your choice.)

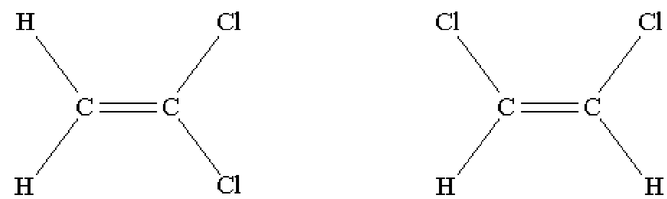
The Model: Dipole-Dipole Forces

A polar compound is one in which there is a separation of charge within a molecule of the substance. Neighboring molecules in a bulk sample of a polar compound will arrange themselves in order to maximize attractive forces and to minimize repulsive forces between the molecules. (Of course, in a liquid there is still enough thermal energy so that the molecules are constantly moving past each other. So this is a "time-averaged" picture we're considering.)
The net attractive forces between polar molecules are called **dipole-dipole forces**. Dipole-dipole forces are typically only about 1% as strong as a covalent bond.

Key Questions

4a. If intermolecular forces are stronger between neighboring molecules in a bulk sample, will it require more or less heat energy to separate molecules from each other? (Circle your choice.)

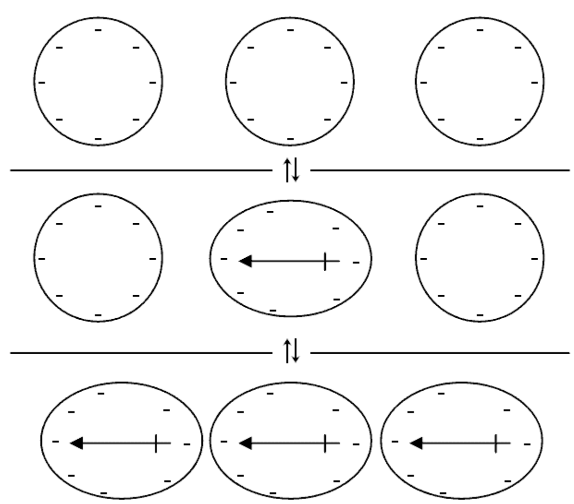
b. Consider the molecules on the right. One of the compounds has a boiling point of 37 °C and the other has a boiling point of 60 °C. Which one has each boiling point? *Explain how you made your decision*.



μ = 1.34 D μ = 1.90 D

The Model: Dispersion Forces (London Forces)

Regardless of whether or not a molecular substance is polar, all gases can be converted into a liquid (or solid) if enough heat is removed. This suggests that there is a second type of intermolecular force that can hold nonpolar molecules together in a liquid or solid. These intermolecular forces are called **dispersion forces** (also known as **London Forces**), which are resultant "induced" dipole moments between neighboring molecules. For example, in neon:



Consider a grouping of (nonpolar) atoms, each being represented as circular with its valence electrons equally distributed about the center. We can imagine that at some particular moment in time the charge cloud of one of the atoms may become distorted, giving the particle a temporary dipole. The charge cloud of the atom may resume its previous spherically-symmetric shape. Alternatively, if other molecules are nearby, the temporary dipole may induce a dipole in them. These **induced dipole moments** are temporary, but neighboring molecules are constantly inducing moments between each other. So it is (again) a time-averaged picture we're considering.

Key Questions

5. Consider the boiling points of the noble gases.

gas	Ne	Ar	Kr	Xe
T_b° (°C)	-245.9	-185.7	-152.3	-107.1

a. Rank the gases in order of increasing strength of intermolecular forces.

b. Rank the gases in order of increasing atomic radius.

c. As the valence charge cloud gets larger, would it be easier or harder for an extra electron to move to one side of the atom, thus giving the particle a temporary dipole moment? (Circle your choice.)

6. Alkanes (C_nH_{2n+2}) are either nonpolar or have very small dipole moments. Methane (CH_4) is a gas at room temperature. Butane (CH_3-CH_2-CH_2-CH_3) is a gas at 25 °C, but the application of a little pressure allows it to be liquefied. Hexane (CH_3-CH_2-CH_2-CH_2-CH_2-CH_3) is a liquid at 25 °C. And icosane [$CH_3(CH_2)_{18}CH_3$] is a solid at 25 °C.

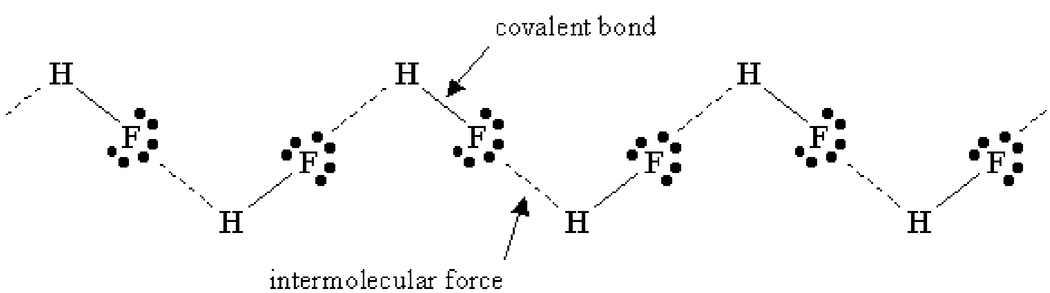
a. What happens to the "surface area" of charge clouds that neighboring molecules can have in contact with each other as the length of the alkane molecule increases?

b. What happens to the strength of the intermolecular forces as the length of an alkane molecule increases?

c. What is the relationship between the size of a molecule's charge cloud and the strength of intermolecular forces?

The Model: Hydrogen Bonding (H–FON Bonding)

A very special kind of dipole-dipole force occurs in a bulk sample of hydrogen fluoride. Consider the following schematic.



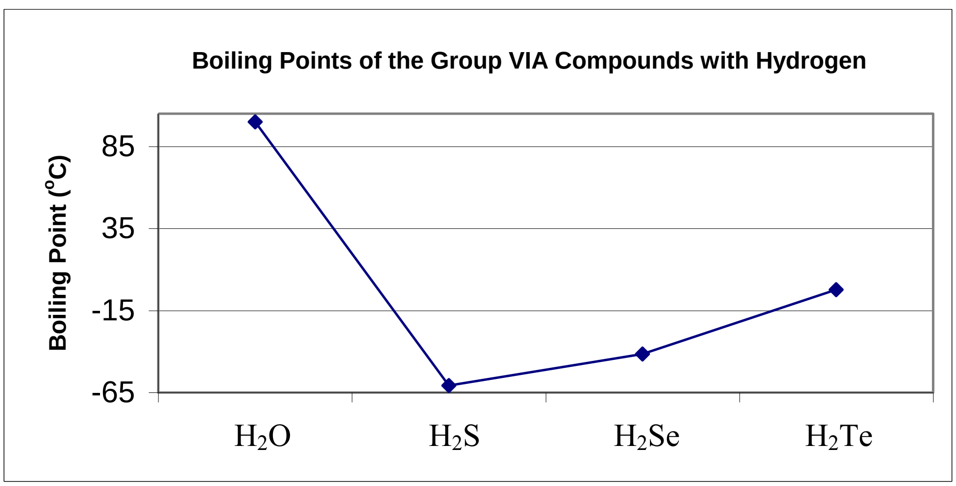
This type of intermolecular force exists in samples of compounds that have O—H and N—H bonds as well. Since all of them involve an atom that is bound to a hydrogen atom, these dipole-dipole forces are (unfortunately) called "**hydrogen bonds**". Hydrogen bonds, typically on the order of 30 kJ/mol, are many times stronger than the ordinary dipole-dipole force (and, thus, the reason they are classified as a distinct type of intermolecular force).

Key Questions

7a. What are two special characteristics of the atoms of H, N, O, and F that sets them apart from other elements? (*Hint*: See your textbook to compare their atomic radii and electronegativities with those of other elements!)

b Use Coulomb's Law ($F \propto Q_+ \, Q_- / r^2$) to explain why hydrogen bonding only occurs in compounds with N—H, O—H, and F—H covalent bonds.

8. Consider the boiling points of the hydrides of the Group VIA elements:



Describe the intermolecular forces that exist in a bulk sample of each compound. Which intermolecular forces predominate (*i.e.*, are the strongest)? Explain why H_2O has the highest boiling point. Explain the trend in boiling point in going from H_2S to H_2Se to H_2Te.

Exercises

9. Identify the ***strongest*** interparticle force in a sample of each of the following.
   a.) $SO_{2\,(l)}$ ______________________ d.) $MgCl_2$ ______________________
   b.) $CF_{4\,(l)}$ ______________________ e.) CH_3F ______________________
   c.) CH_3OH ______________________

10. Circle the member of each pair of compounds forms intermolecular hydrogen bonds and draw and label the H-bonded structures in each case.
    a.) $(CH_3)_2NH$ or $(CH_3)_3N$ b.) $HOCH_2CH_2OH$ or FCH_2CH_2F

11. Which member of each pair has the greater polarizability—i.e. which member of each pair will most form stronger dispersion forces? Briefly explain your reasoning.
    a.) Ca^{2+} or Ca

    b.) CH_3CH_3 or $CH_3CH_2CH_3$

    c.) CCl_4 or CF_4

12. Circle the member of each pair that has the ***greater*** boiling point? Briefly explain your reasoning. Your explanation must include the nature of the intermolecular forces involved.
    a.) CH_3CH_2OH or $CH_3CH_2CH_3$

    b.) NO or N_2

    c.) H_2S or H_2Te

13. Which would you expect to have the ***lower*** boiling point, $CH_3CH_2CH_2CH_3$ or cyclobutane (C_4H_8)? Circle your choice and briefly explain your reasoning. Your explanation should include the nature of the intermolecular forces involved.