Intermolecular Nonbonding Forces Exercise
Dr. Gergens - SD Mesa College

Introduction

The way electrons orient with respect to each other about atoms or molecules give rise to chemical unions between atoms or physical attractions between molecules and atoms; see the concept map for bonding on the previous page.

Forces between atoms in molecules are induced by the way in which the electrons distribute themselves around nuclei. When the electrons are shared between nuclei and they induce powerful chemical bonding forces that join nuclei into molecules. The chemical bonds within a molecule are typically quite strong, such that it's usually necessary to heat a molecule to very high energies before the chemical bonds begin to break. A typical covalent chemical bond has a bond energy or bond dissociation energy of about 100 kcal/mol (400 kJ/mol).

Even when the electrons don't cause an actual chemical bond to form, they still induce nonbonding forces that cause atoms or molecules to influence each other. The physical attractive forces between molecules are called intermolecular forces. Since the forces of attraction are physical, not chemical, sometimes we refer to the forces of attraction as being nonbonding forces of attractions.

Molecules exist as distinct, separate collections of matter. We commonly think of three classes of forces between molecules. The three classes of forces are:

```
hydrogen bonding > dipole-dipole (or simply polar) forces > London dis
  10 kcal/mol              1 kcal/mol                   0.1 kcal/mol
```

A rough estimate of the total amount of energy required to separate molecules very far away from each other is listed with the force. Note, the rough estimate is a decrease of ten-percent (10%) total energy is

Purpose

In this experiment, you will use structural and graphical analysis to study the intermolecular forces of various compounds.

Getting Started

a. Your instructor will present a discussion over intermolecular nonbonding forces. You may also want to review your old general chemistry notes and textbook covering this topic.

   http://homework.sdmesa.edu/dgergens/chem231L/forces/forces.html

b. You will need to graph and word process this assignment, placing your answers into appropriate cells (boxes) in this document. Download the Microsoft Word file <<force.doc>> following the quidelines at the URL about or (click here).

c. Review the graphing tutorial provided at

   http://homework.sdmesa.edu/dgergens/chem231L/forces/forces.html

   The graphing tutorial covers the steps to graph the data in Problem 1 given in this exercise. You will need to download and install QuickTime Movie Player if you do not have it on your home computer to view the movie. This link is available at the tutorial site as well.

d. Graph the data for problems 2 and 3 using the “Boiling Point” data given and any graphing program of your choice.

e. Select all data in the given cells in problem 2, cut and paste the data into an Excel spread sheet as demonstrated in the graphing tutorial or re-type / input the given “Boiling Point” data into a graphing program.

f. Using a graphing program of our choice, your final graphs should appear like Graph 1 for data given in Problem 1.
   Plot boiling point (y-axis) versus molar mass (x-axis), overlaying each subset of data. Include appropriate labels as in the example

g. Copy and paste your graph for problem 2 into the appropriate table cells in the <<force.doc>> word document.

h. Repeat this for problem 3.

i. Save your work.

j. Once your have your graphs and your work is saved, read the following discussion, and answer the questions.

Boiling Point Data

The **boiling point** of a compound is the temperature at which a compound turns from a liquid to a gas or a gas to a liquid. This temperature is a true measure of the forces of attractions between molecules as molecules separate from one another when they turn from a liquid to a gas. Below are boiling point and molar mass data sets of several compounds. You will need to graph these data sets.

If you have not done so, watch the tutorial at

http://homework.sdmesa.edu/dgergens/chem231L/forces/forces.html

The graphing tutorial covers the steps to graph the data in problem 1 given in this exercise. The graph for problem 1 is shown on the next page. Then graph the data for problems 2 and 3. After you have graphed the data for problems 2 and 3, read through the discussion section and answer the questions. Word-process this exercise using the Microsoft Word file <<force.doc>> available from the link above.

Problem 1 **Effect of Molar Mass on Boiling Points of Molecular Substances**

Noble Gases			Halogens			Hydrocarbons		
	MM	bp (°C)		MM	bp (°C)		MM	bp (°C)
He	4	-269	F_2	38	-188	CH_4	16	-161
Ne	10	-246	Cl_2	71	-34	C_2H_6	30	-88
Ar	40	-186	Br_2	160	59	C_3H_8	44	-42
Kr	84	-152	I_2	254	184	n-C_4H_{10}	58	0

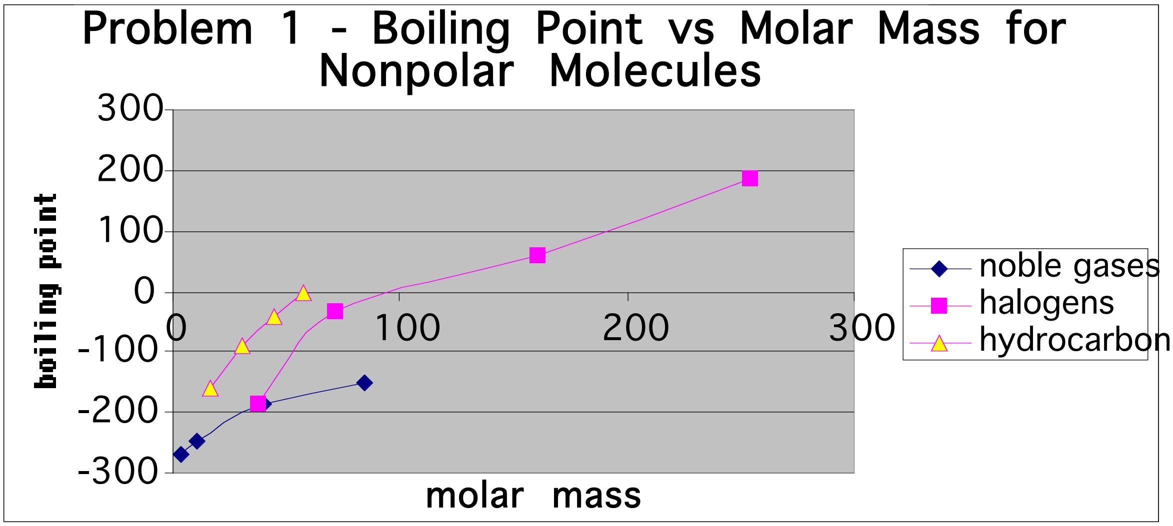
Problem 2 **Boiling Points of Polar versus Nonpolar Substances**

Polar Substances						Nonpolar Substances		
hydrogen bonding			dipole-dipole			dispersion		
	MM	bp (°C)		MM	bp (°C)		MM	bp (°C)
NH_3	17	-33	CO	28	-192	N_2	28	-196
H_2O	18	100	PH_3	34	-88	SiH_4	32	-112
HF	20	20	AsH_3	78	-62	GeH_4	77	-90
CH_3OH	32	65	ICl	162	97	Br_2	160	59

Problem 3 **Boiling Points for Various Hydrides**

Group 4			Group 5			Group 6			Group 7			Group 8		
	MM	bp(°C)		MM	bp(°C)		MM	bp(°C)		MM	bp(°C)		MM	bp(°C)
CH_4	16	-161	NH_3	17	-33	H_2O	18	100	HF	20	20	He	4	-296
SiH_4	32	-112	PH_3	34	-88	H_2S	34	-60	HCl	36.5	-85	Ne	10	-246
GeH_4	77	-90	AsH_3	78	-62	H_2Se	81	-41	HBr	81	-67	Ar	40	-186
SnH_4	123	-47	SbH_3	125	-17	H_2Te	130	-4	HI	128	48	Kr	84	-152

Boiling Point Versus Molar Mass Graphs



Select this cell, and paste your Problem 2 Graph.

Select this cell, and paste your Problem 3 Graph.

Discussion

Graph 1 shows the relationship between three classes of nonpolar substances; noble gases, halogens, and hydrocarbons. There are two trends that we can examine in Graph 1. The first is the relationship between boiling point and molecular weight. For each class of compound, as molecular weight increases there is a corresponding increase in boiling point. The second trend that we can observe in Graph 1 is shown by comparing the boiling points of molecules from different categories that have similar molecular weight. Ar, F_2, and C_3H_8, have similar molecular weights, but their respective boiling points are -186, -188, and -42 °C. To understand the difference in boiling points we must examine the structure of these molecules and determine the types of intermolecular forces between molecules. The shape of molecule is also a factor in determining the magnitude of dispersion forces. Because the surface between these molecules are different, the dispersion forces between these molecules will vary. Molecules that are structurally large have stronger dispersion forces because the area of contact between molecules in general is greater.

Graph 2 shows the relationship between polar and nonpolar substances and three classes of nonbonding forces; dispersion, dipole-dipole, and hydrogen bonding. There are two trends that we can examine in Graph 2. The first is the relationship between boiling point and molecular weight. As molecular weight increases there is a corresponding increase in boiling point. CO, PH_3, AsH_3, and ICl are within the same category with their respective boiling points as -192, -88, -62 and 97 °C. The second trend that we can observe in Graph 2 is shown by comparing the boiling points of molecules from different categories that have similar molecular weight. PH_3 and SiH_4 have similar molecular weights, but their respective boiling points are -62 and -90 °C. The dispersion force in SiH_4 is weaker than the dipole-dipole force in PH_3. The high boiling points of H_2O, HF, and NH_3 violate the trend in which small molecules boil at lower temperatures than larger molecules that are otherwise similar. This indicates that for small molecules in particular, hydrogen bonding cause exceptionally strong intermolecular nonbonding attractions.

Graph 3 illustrates intermolecular nonbonding attractions between various periodic groups of hydrides. The boiling points of these different groups of hydrides show how dipole-dipole, dispersion forces based on molecular size, and hydrogen bonding affect intermolecular attractions.

Questions:

1. In Graph 1, the higher boiling points of low molecular weight hydrocarbons violate the general trend. "molecular size is related to molar mass," in which lower molecular weight molecules boil at lower temperatures than higher molecular weight molecules. State the reason why there is a violation in the general trend observed for hydrocarbons. (Hint: Make molecules of these substances and consider molecular size).

2. In Graph 2, the high boiling point of H_2O violates the general trend in which a small molecule boils at lower temperature than a large molecule that is otherwise similar. State why H_2O is higher boiling than methanol, CH_3OH.

3. In Graph 3, H_2Se, AsH_3, and GeH_4 are about the same size (nearly equal molar mass), and none of them have hydrogen bonding. State why H_2Se is highest boiling of the three.

4. The Group 4 hydrides all have tetrahedral structures. They are nonpolar, and they have no hydrogen bonding. The only intermolecular nonbonding force is dispersion. State why CH_4 is lowest boiling and SnH_4 is highest boiling.

5. Predict on the basis of molecular shape, molecular size, molecular polarity, and hydrogen bonding, which member of each set of compounds has the higher boiling point. State the reason for each choice. Assume that molecular size is related to molar mass.

CO_2 SO_2	CO_2 CS_2
CH_4 CBr_4	trimethyl amine n-propyl amine
n-butane n-propane	dimethyl ether ethanol

6. The data table shows the relationship between three classes of organic compounds, alkanes, aldehydes, and carboxylic acids. Graph the given data and paste Graph 4 into this document, and answer the question at the bottom of the page.

Problem 4 Boiling Points of Three Classes of Organic Compounds

Polar Substances						Nonpolar Substances		
hydrogen bonding			dipole-dipole			dispersion		
	MM	bp (°C)		MM	bp (°C)		MM	bp (°C)
butanoic acid	88	164	butanal	72	76	butane	58	0
pentanoic acid	102	186	pentanal	86	103	pentane	72	36
hexanoic acid	116	205	hexanal	100	128	hexane	86	69
heptanoic acid	130	223	heptanal	114	153	heptane	100	98
octanoic acid	144	239	ocatanal	128	171	octane	114	126

Graph 4

Select this cell, and paste your Problem 4 Graph.

There are two trends that we can examine. Give a brief written discussion of these two trends.