CHM 130LL: States of Matter

Introduction

Substances can exist in three physical states: solid, liquid or gas. The difference between these physical states is the the molecules' freedom of movement and the amount of space between molecules. This is related to the attraction between molecules (intermolecular forces) and the temperature.

In the **solid** state, molecules are close together in a rigid structure. This keeps both the shape and the volume of the solid constant. Molecules in a **liquid** slide back and forth, but still feel the intermolecular forces of adjacent molecules. Thus, liquids flow, but are restricted to a constant volume. Most molecules move independently in a **gas**, barely feeling the intermolecular forces. There is a great deal of empty space between atoms and molecules in a gas. Thus, a gas will fill a container completely and assume its shape. Compressing a gas reduces the amount of empty space between molecules (and under certain conditions, gases can actually be liquefied this way). In this experiment, you will explore and compare the relative compressibility of liquids and gases, and you will compare the densities of various solids, liquids, and gases.

Matter can gain or lose energy. When you apply heat to a substance, one of two things occurs, depending on the melting and boiling points of the substance being heated.
If the added heat **does not cause** a phase change, the molecules increase their ***kinetic energy*** (i.e. energy associated with the motion) and move faster. Increasing the rate of molecular motion increases the temperature of a substance. In this case, the added energy increased the kinetic energy (speed) of the molecules.

Gas molecules exert **pressure** whenever they collide with the surface of their container; the more often they collide with the surface, the greater the pressure. The pressure of a gas can be manipulated by changing the kinetic energy of the gas molecules. Because gases expand and contract depending on various conditions, manipulating the kinetic energy of the gas molecules can also affect the volume occupied by a gas. In this experiment, you will explore the behavior of gases under different conditions to determine the effects of temperature, mass, and the number of molecules on the pressure and the volume of a gas.

Work in pairs

Procedure

A. Compressibility of Gases and Liquids

1. Obtain a syringe and fill with air. Push the barrel in slightly to adjust to the largest readable volume, and place the tip snugly against your fingertip. You now have a “trapped” air sample. Record its volume.
2. Hold the syringe vertically (needle down) and increase the pressure on the top of the syringe by pushing directly down on the barrel. Record the smallest volume obtained.
3. Using the markings on a 50-mL beaker, pour about 20 mL of deionized water into the beaker. Fill the syringe with deionized water water. Remove any air bubbles when you invert the syringe, and adjust the volume. Avoid any water leakage during the experiment. Repeat the experiment once more.
4. Answer the question on compressibility and explain based on your observations.

B. Density Comparison

Note: *Gases cannot be weighed directly in air because of the "buoyancy effect"—the same effect that causes you to feel "lighter" in the water than out of it. You will produce a gas with a chemical reaction, and weigh all the products* ***except*** *the gas. By subtracting the mass the products (except the escaped gas) from the reactants, you can calculate the mass of the gas produced.*

CAUTION: Hydrochloric acid is corrosive and can burn skin and damage clothing. Rinse spills on your skin immediately with water for 15 minutes. Neutralize, wash up, and wipe up spills on the lab bench immediately.

1. Obtain a vial of calcium carbonate from the instructor's station.
2. Check the balloon provided for holes. If there are holes, replace the balloon. Add the sample of $CaCO_3$ to the balloon. ***Do not wash or rinse the test tube.*** Return the unwashed, dry test tube to the instructor's station.
3. Pour about 20 mL of 2M hydrochloric acid, HCl*(aq)*, into a 50-mL beaker. Use the markings on the beaker to estimate 20 mL. Transfer the acid to the Erlenmeyer flask.
4. Place the balloon over the neck of the Erlenmeyer flask without getting any $CaCO_3$ into the flask. Weigh the entire setup. Record the "mass of the apparatus + reactants".
5. Remove the apparatus from the balance. Invert the balloon over the flask opening, and shake the powdered $CaCO_3$ into the acid. The gas produced is CO_2 (carbon dioxide).
6. When the balloon has reached maximum size, **estimate** its volume (to within 50 mL) by comparing it to the volumetric flasks provided near the instructor's station. For example, if the volume of the balloon is halfway between the 150 mL flask and the 250 mL flask, estimate the volume as 200 mL.
7. Slip the balloon off the Erlenmeyer flask to allow the CO_2 to escape. Reattach the balloon and weigh the setup again. This is the "mass of the apparatus + all products except the CO_2". **Do not throw away the balloon!** It can be used by the next group.
8. Calculate the mass of the CO_2 using conservation of mass.

$$\text{mass of } CO_2 = \begin{pmatrix}\text{mass of apparatus} \\ + \text{ reactants}\end{pmatrix} - \begin{pmatrix}\text{mass of apparatus} \\ + \text{ all products except } CO_2\end{pmatrix}$$

9. Next, calculate the density of the CO_2 gas in g/mL.

Waste: Dispose of all used solutions and reagents in the waste container in the hood. Squeeze any excess solution from the disposable pipets into the waste container in the hood, then dispose of used pipets in the trash.

Liquids: Liquids can be weighed in a container, and the mass of the container subtracted to obtain the mass of the liquid.

1. Weigh an empty 10-mL graduated cylinder, and record the mass.
2. Use a disposable pipet to add 10.00 mL of water. Reweigh, and record the new mass.
3. Calculate the mass of 10.00 mL of water.
4. Record the volume. Calculate the density of water in g/mL using **10.00 mL** as the volume of water.

Solids: Nonreactive solids (glass, pieces of metal, plastic, wood) can be weighed directly on the balance. However, chemicals used for experiments must be weighed in containers.

1. Choose a solid from the tray and weigh it. Each solid has a volume approximately equal to 10 mL. Note the material used.
2. Calculate the density of your solid in g/mL using 10.0 mL as the volume of the solid.
3. Answer the question comparing the densities of gases to the densities of liquids and solids.

Computer Activity

Launch **Safari** by clicking on the icon, , at the bottom of the screen. Maximize the browser window by clicking on the green button at the upper, left-hand side of the window. Now, go back to Favorites menu and choose **"Molecules in Motion."** If the Web site is not listed, go to the following:

http://mc2.CChem.Berkeley.EDU/Java/molecules/index.html

The ***Network Login-Logout Page*** should automatically load in Safari when you try to access an external site. Use your Palette username and password to login to the network.

When the **"Molecules in Motion"** page has loaded, scroll down until you see the four buttons at the bottom: For Fixed Pressure, About, Reset Containers and Remove Barrier.

The "Molecules in Motion" Java applet illustrates how the motion of gas molecules is affected by temperature, the mass of the molecules, and the number of molecules present in a sample.

The **"Fixed Volume"** mode demonstrates the effect of ***temperature***, the ***mass*** of the molecules, and the ***number*** of molecules on the ***pressure*** of the system.

The **"Fixed Pressure"** mode demonstrates the effect of ***temperature***, the ***mass*** of the molecules, and the ***number*** of molecules on the ***volume*** of the system.

Note: You can manipulate the temperature, the number of molecules, and the mass of each molecule using the sliders or by highlighting then re-entering numbers directly into the boxes then pressing Enter.

Exploring the Motion of Gas Molecules

Make sure you are in **"Fixed Volume" mode**. You should see four buttons at the bottom of the window. If you do not see four buttons, consult your instructor.

1. Slide the **Temperature** for the **Red molecules** all the way to the left to **1 K**. How does the speed of the Red molecules at the lower temperature compare to the ***speed*** of the Blue molecules? Use the pressure gauge displayed at the bottom of the screen to determine how the ***Internal Pressure*** changes when the ***Temperature*** is decreased? Are **temperature** and **pressure** related **directly** or **indirectly**?

Note: Two variables are related directly if increasing one variable results in the increase of the second; conversely, they are related inversely if increasing one variable results in the decrease of the second.

2. Press the **“Reset Containers”** button (third button at the bottom of the screen). Slide the **Number** of the Red molecules all the way to the right to **99**. How does the ***Internal Pressure*** change when the ***Number of molecules*** is increased? Are ***number of molecules*** and ***pressure*** related **directly** or **inversely**?
3. Press the **“Reset Containers”** button (third button at the bottom of the screen). Next change the **mass** of the **Red molecules** to **by entering 100** (then Enter) for the **Mass** in amu. How does the speed of the more massive Red molecules compare to the speed of the less massive Blue molecules at 273K? How does the ***Internal Pressure*** change when the ***mass*** is increased?
4. Next change the **Mass** of the **Blue molecules** to **by entering 100** (then Enter) for the **mass** in amu. Change the **Number** for both the Red and Blue molecules **by entering 50** (then Enter). Press the **“Remove Barrier”** button (right-most button at the bottom of the screen). What happens to the molecules when they are allowed to move within the same container?
5. Press the **“Reset Containers”** button (third button at the bottom of the screen). Change the **Mass** of both the **Red and Blue molecules** to **by entering 100** (then Enter). Change the **Number** for both the Red and Blue molecules **by entering 50** (then Enter). Now slide the **Temperature** for the **Red molecules** all the way to the left to **1 K**. Observe the motion of the molecules for 1 minute. What occurs with the slower Red molecules that does not occur with the Blue molecules?
6. Slide the **Mass** of the Red molecules all the way to the right to **199 amu**. Is the clustering of Red molecules affected by the increased mass? Slide the **Number** of the Red molecules all the way to the right to **99**. Is clustering affected by the increasing the number? If larger clusters continue to form, predict what will happen to the gas.
7. Press the **“For Fixed Pressure”** button (left-most button at the bottom of the screen). In this mode, the container size will vary to keep the pressure inside the container equal to 1. Slide the **Temperature** for the **Red molecules** all the way to the right to **999K**. How does the container ***Volume*** change when the ***Temperature*** is increased? Are **temperature** and **volume** related **directly** or **inversely**?
8. Press the **“Reset Containers”** button (third button at the bottom of the screen). Slide the **Mass** of the **Red molecules** all the way to the right to **199 amu**. How does the container ***volume*** change when the ***mass*** is increased?
9. Press the **“Reset Containers”** button (third button at the bottom of the screen). Slide the **Number** of the **Red molecules** all the way to the right to **99**. How does the container ***volume*** change when the ***number of molecules*** is increased? Are **number of molecules** and **volume** related **directly** or **inversely**?
10. Slide the **Mass** of the **Red molecules** all the way to the right to **199 amu**. Slide the **Temperature** all the way to the left to **1 K**. Note that the Red molecules are still constantly moving, but now there is almost no space between each molecule. What is the physical state of the sample now? Explain.

Computer Network Logoff

Note: Be sure to logoff the network using the *Network Login-Logoff Page* **(under the Favorites menu or Favorites Toolbar)** when you are done with the computer.

LAB REPORT

CHM 130LL:
States of Matter

Name: ______________________

Partner: _____________________

Section Number: _______________

A. Compressibility of Gases and Liquids

Volume of air sample: (Note: 1 cc ≡ 1 cm^3)

original sample __________ cm^3 under maximum pressure __________ cm^3

Volume of water sample:

original sample __________ cm^3 under maximum pressure __________ cm^3

Which is more compressible? (Circle one) water air

Explain why based on how particles exist at the molecular level.

B. Density Comparison of Solids, Liquids, and Gases

Gases: Mass apparatus + reactants _____________

Mass apparatus + all products except CO_2 _____________

Mass CO_2 produced _____________

Estimated volume of CO_2 in balloon _____________

Show calculation for density below:

Density of CO_2 gas _____________

Liquids: Mass graduated cylinder + 10.00 mL of H_2O _____________

Mass of empty graduated cylinder _____________

Mass of 10.00 mL of H_2O _____________

Show calculation for density below (using **10.00 mL** for the volume of H_2O):

Density of H_2O _______________

Solids:

Material used: (Circle one) metal wood glass

Mass of solid sample ________________

Show calculation for density below (using **10.0 mL** for the volume of the solid) :

Density of solid (in g/mL) ________________

Explain why the density of CO_2 (and other gases) is so much lower than the density of liquids and solids based on how the particles exist at the molecular level.

Computer Activity Questions:

Molecules in Motion

1. a. The Red molecules at the lower temperature move _______ than the Blue molecules? (Circle one) **faster** **slower**

   b. Internal Pressure _____ when Temperature increases. **increases** **decreases**

   c. Temperature and Internal Pressure are related _____. **directly** **inversely**

2. a. Internal Pressure _______ when Number increases. **increases** **decreases**

   b. Number and Internal Pressure are related _______. **directly** **inversely**

3. a. The more massive Red molecules move _______ than the Blue molecules? (Circle one) **faster** **slower**

   b. Mass and Internal Pressure are _______ related. **directly** **inversely** **not**

4. What happens to the molecules when they are allowed to move within the same container?

5. What occurs with the slower Red molecules that does not occur with the Blue molecules?

6. a. Does the clustering of molecules increase when number in increased? **Yes** **No**

   b. If more atoms combine and clusters continue to grow larger, predict what will happen to the gas.

7. a. Volume _______ when Temperature increases. **increases** **decreases**

   b. Temperature and volume are related _______. **directly** **inversely**

8. Mass and volume are _______ related. **directly** **indirectly** **not**

9. a. Volume _______ when Number increases. **increases** **decreases**

   b. Number and volume are related _______. **directly** **inversely**

10. What is the physical state of the sample when the temperature is 1K, the mass is 199 amu, and there are 99 molecules? (Circle one below)

    solid liquid gas

    Explain your answer based on the appearance of the sample.

Note: Be sure to logoff the network using the ***Network Login-Logoff Page*** **(under the Favorites menu or Favorites Toolbar)** before you logoff the computer using the Apple menu (top left corner of the screen).