During Class Inventions and Computer Lab Activities

GENERAL CHEMISTRY

Volume I

3RD EDITION

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During Class Inventions and Computer Lab Activities

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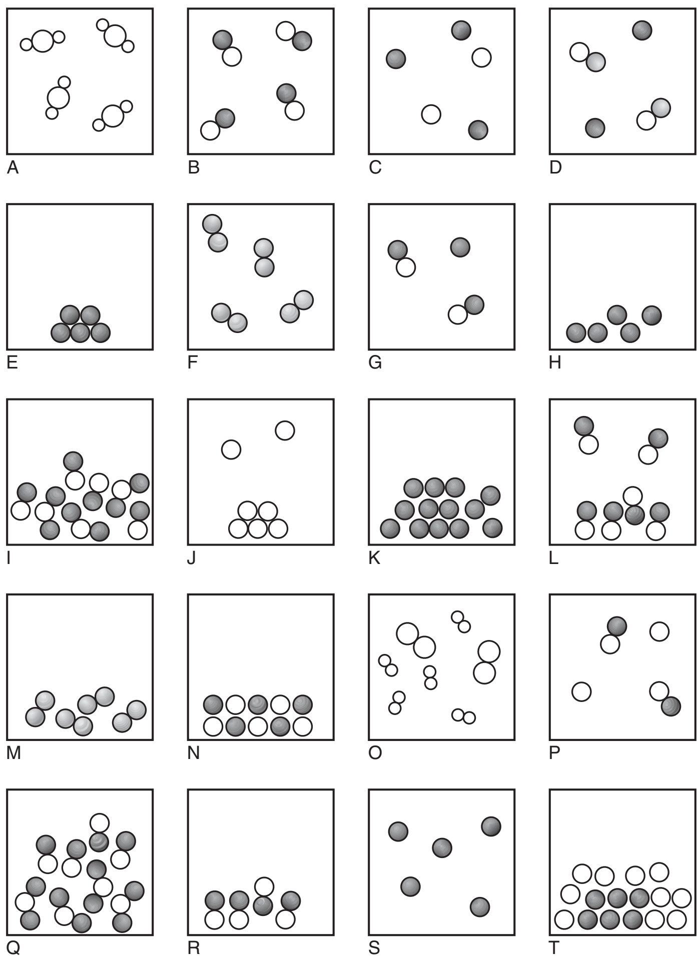
* The bulk of the activities in this section were originally developed and tested by John Gelder. Some of the activities were developed by Michael Abraham. Others were developed and tested by Thomas Greenbowe, Marilyn Stains, and Nihal Kaissieh at the University of Arizona and Iowa State University.

CLASSIFICATION OF MATTER*

NAME ______________________ SECTION ______________________

1. Each container (A–T) shows a sample of substance(s) as viewed at the atomic level. Look at the containers and come up with some different ways to categorize the contents. For example, if you feel the contents of a subset of the containers could all be grouped, what would be the basis for the group?



Thoughts/ideas/comments:

* Inspired by James, Helen J. and Nelson, Samuel L. A Classroom Learning Cycle: Using Diagrams to Classify Matter. *Journal of Chemical Education* 58, 476, 1981.

2. Select one or more containers from 1 that represent:

   a. a chemical change (briefly explain your reasoning for the choice)

   b. a physical change (briefly explain your reasoning for the choice)

3. Complete the containers below by representing a solid substance in a liquid, before and after it dissolves. Include a brief narrative supporting your diagrams. Is dissolving a physical or chemical change?

Before | After

4. Describe the contents of four containers (below) that you have not selected for question 2. Clearly describe the contents of the container such that the description fits that container and no other container.

Container	Description

DENSITY

Name

Section

1. When a marble is dropped into a beaker of water, it sinks to the bottom. Which is the best explanation?

   a. The surface area of the marble is not large enough to be held up by the surface tension of the water.

   b. The mass of the marble is greater than that of the water.

   c. The marble weighs more than the equivalent volume of the water.

   d. The force from dropping the marble breaks the surface tension of the water.

   e. The marble has greater mass and volume than the water.

   Justify your choice. For the choices you did not pick, explain what is wrong with each statement.

2. Consider the following compounds and their densities.

Substance	Density (g/mL)	Substance	Density (g/mL)
Isopropyl alcohol	0.785	Toluene	0.866
n-Butyl alcohol	0.810	Ethylene glycol	1.114

   100 mL of each liquid is placed in its own graduated cylinder.

   a. If the label on each graduated cylinder got lost, how would you be able to identify which graduated cylinder contains which chemical?

   b. Is density an intensive or an extensive property of matter?

3. You have a 1.000 cubic centimeter sample of lead (density = 11.34 g/cm^3), a 1.000 cubic centimeter sample of glass (density = 2500 kg/m^3), and a 1.00 cm^3 sample of ebony wood (density = 960 kg/m^3) and balsa wood (density = 170 kg/m^3). You drop each in separate beakers of water each containing 250 mL of water.

   How do the volumes of water displaced by each sample compare? Explain.

4. Gold can be hammered into thin sheets called gold leaf. You have 2 gold leaves that your grandmother gave you as a gift.

   a. Your grandmother told you that the first one was made from a 305 mg piece of gold that has been hammered into a sheet measuring 2.44 ft × 1.12 ft. What is the average thickness of the sheet in meters, using scientific notation? (Density = 19.32 g/cm^3)

   b. The other gold leaf was made from a 650 mg piece of gold leaf that has been hammered into a sheet measuring 3 cm × 3 cm × 0.00374 cm. What is the density of this gold leaf?

   c. If you were to sell these two sheets of gold on e-Bay, what would you expect to sell it for? (Google the current cost of gold per ounce.)

MEASUREMENT AND ERROR

Name ____________________ Section ____________________

1. Bridges on the Kansas State Turnpike have the distance from the beginning of the turnpike to the bridge printed on the side of the bridge. The bridge in the picture has a mileage of 110.820 (miles) printed on the south (maybe the west) side of an overpass bridge crossing on the turnpike. The distance printed on the opposite side of the overpass bridge is also 110.820 miles. Assuming the Kansas Department of Transportation (KDOT) uses a global positioning system device accurate to within ±1.5 meters:

   a. Express the error in measuring accuracy of the GPS device used by KDOT in + or – terms in units of feet (show your work).

   b. Express the error in measuring accuracy of the GPS device used by KDOT in + or – terms in units of miles (show your work).

c. Is the mileage number written on the bridge overpass reported to a reasonable number of significant figures? Explain.

2. Consider that the width of a four-lane overpass is 18 meters. Is it reasonable to report the distance as the same number (110.820 miles) on opposite sides of this overpass? Explain.

3. Would it be reasonable to use "111 miles" as the distance measure on both sides of the overpass? Explain.

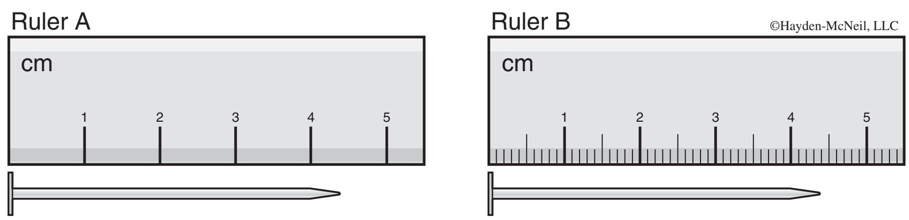
4. What number should be reported if the same number is to be printed on both sides of the overpass? Explain.

MEASUREMENT

Name

Section

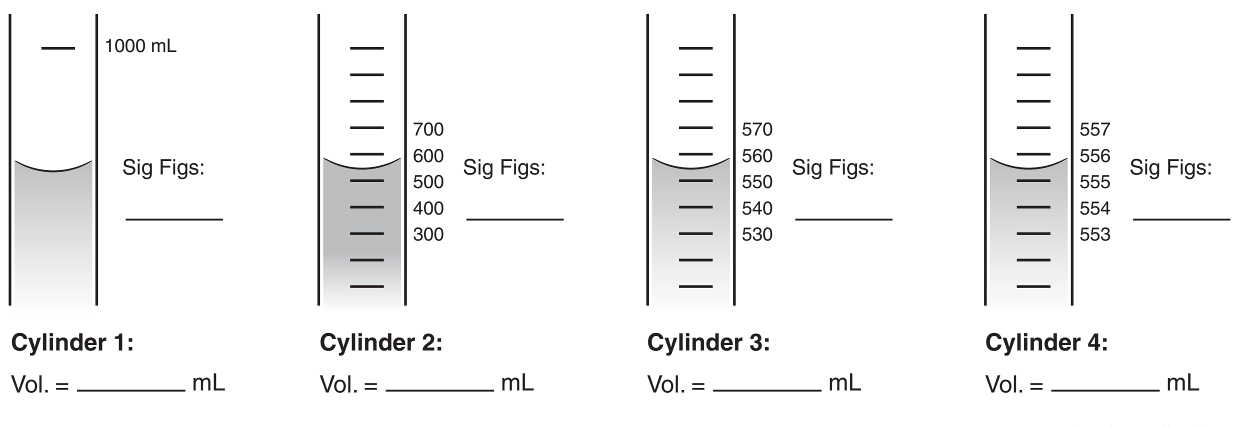
1. What is the length of the nail according to ruler A and ruler B?



Which one is more precise?

How many significant figures are in this measurement?

2. What is the amount of water in each of these cylinders? Which one is more precise?



How many significant figures are in each of these measurements?

3. a. The diameter of the sun is 1,390,000 km. In scientific notation this is: __________

   b. What is the surface area of the sun in km^2 and in $mile^2$? ___________________

   c. What is the volume of the sun in km^3 and in $mile^3$? ______________

   d. The mass of the sun is 1.989×10^{30} kg. What is the average density of the sun in:

      i. kg/km^3?

      ii. g/cm^3?

4. Calculate the volume of a backpack in cm^3, m^3, and in^3 whose dimensions are 22.86 cm × 38.0 cm × 76 cm.

SIGNIFICANT FIGURE PRACTICE

Name ______________________________ Section ______________________

1. Indicate the number of significant digits in each of the following measurements.

   a. 23.500 g ____________

   b. 100.35 mL ____________

   c. 1.004×10^{-7} m ____________

   d. 0.00230 kg ____________

2. Round off the following numbers to the indicated number of significant figuress.

   a. 0.0089346 kg (3 sig figs) ____________

   b. 96515 mL (3 sig figs) ____________

   c. 3.50492 m (3 sig figs) ____________

3. Determine the result to the correct number of significant figures.

   a. $\left(\frac{3.2\text{ cm} \times 1.23\text{ cm} \times 0.5\text{ cm}}{8.32\text{ cm} \times 1.000\text{ cm} \times 0.500\text{ cm}}\right) =$ ____________

   b. $\left(\frac{2.420\text{ g} + 15.6\text{ g}}{5.31\text{ g}}\right) =$ ____________

   c. $\left(\frac{6.00\text{ g}}{16.1\text{ mL} - 8.440\text{ mL}}\right) =$ ____________

4. Perform the following conversions (1 lb = 453.59 g; 1 L = 1.0567 qt; 1 inch = 2.54 cm):

   a. 100. km to miles (use at least 3 conversion factors).

   b. A liquid has a critical temperature of 154.4 K; calculate the temperature in °F and °C.

   c. The thickness of a human hair is approximately 70,000 nm; calculate the thickness in millimeters.

   d. A typical soft drink container is 355 mL; determine the number of quarts of the soft drink container.

5. Perform the following conversion: The density of water is 1.00 g/cm^3. Convert to pounds/foot^3.

WEIGHTED AVERAGE*

Name ______________________ Section ______________________

1. Suppose we have a collection of 15 marbles in a container. 40% of the marbles are red and 60% of the marbles are black. The mass of a single red marble is 6.00 grams and the mass of a single black marble is 8.00 grams.

   a. Calculate the average mass of the marbles in the container. (Clearly show how you arrived at your answer.)

   b. Do any marbles in the container have the same mass as the average mass?

2. Suppose we have another collection of 40 marbles in a different container. 40% of the marbles are red and 60% of the marbles are black. The mass of a single red marble is 6.00 grams and the mass of a single black marble is 8.00 grams. Calculate the average mass of the marbles in the container.

* Inspired by Moog, R.S. and Farrell, J. J. *Chemistry: A Guided Inquiry*. John Wiley, Sons. New York, 1996. Page 5.

3. Outline your strategy for calculating the average mass of a collection of red and black marbles if the total number of marbles is not known.

4. Suppose we have a collection of marbles in a container. 20% of the marbles are orange and 80% of the marbles are white. The mass of a single orange marble is 4.00 grams and the mass of a single white marble is 10.00 grams. Calculate the average mass of the marbles in the container.

5. The element boron is composed of two different isotopes, ^{10}B and ^{11}B. The percent abundance of ^{10}B is 19.78% and the percent abundance of ^{11}B is 80.22%. The relative atomic mass of ^{10}B is 10.01294 u and the relative atomic mass of ^{11}B is 11.00931 u. Calculate the (relative weighted) average atomic mass of boron.

6. If you could reach in and pick a single atom from a sample of boron, what would be the most probable mass of the atom of boron you selected? Explain.

ISOTOPE PRACTICE

Name ______________________ Section ______________________

1. The element chlorine is composed of two different isotopes, ^{35}Cl and ^{37}Cl. The percent abundance of ^{35}Cl is 75.53% and the percent abundance of ^{37}Cl is 24.47%. The relative atomic mass of ^{35}Cl is 34.96885 u and the relative atomic mass of ^{37}Cl is 36.96590 u.

   a. Set up the mathematical equation that you would use to solve this problem and substitute the values for all known quantities.

   b. What does the sum of the fractional abundances of the two isotopes of chlorine add to? Explain.

2. The two naturally occurring isotopes of potassium with reasonable abundance are ^{39}K and ^{41}K. The atomic masses of these two isotopes are 38.9637 u and 40.9618 u. If the relative weighted average atomic mass for potassium is 39.10 u, calculate the fractional abundance of each isotope in nature assuming these are the only two important isotopes for potassium.

   a. Show the mathematical setup.

   b. Solve.

3. The atomic mass for a proton is 1.00727 u and for a neutron the atomic mass is 1.00886 u.

   a. How many protons and neutrons in each isotope of potassium listed in Question 2?

   b. Calculate what the atomic mass of the isotope ^{39}K and the isotope ^{41}K should be, using your answers in part a and the information given in the stem of this problem.

   c. Explain why the mass you calculated in part b for each isotope does not agree with the mass for these two isotopes in Question 2.

NOMENCLATURE PART I

Name ______________________ Section ______________

1. If we tell you that:

Ionic compounds	Covalent compounds
NaCl is called sodium chloride	SO_2 is called sulfur dioxide
$BaBr_2$ is called barium bromide	N_2O_5 is called dinitrogen pentoxide
K_2SO_4 is called potassium sulfate	N_2O is called dinitrogen monoxide

Using the formula, how would you distinguish between ionic and covalent compounds?

Rule(s) for ionic compounds	Rule(s) for covalent compounds

2. Using the information from Question 1, name the following compounds.

$FeCl_2$	HCl (g)
$FeCl_3$	HCl (aq)
CuCl	H_2S (g)
$CuCl_2$	H_2S (aq)

Write rules for naming each of two sets of compounds, using compounds from Questions 1 and 2.

Rule(s) for ionic compounds	Rule(s) for covalent compounds

3. If we tell you that:

ClO_4^- is called **perchlorate ion**
ClO_3^- is called **chlorate ion**
ClO_2^- is called **chlorite ion**
ClO^- is called **hypochlorite ion**

What is the rule?
(Hint: look at number of oxygen)

Per _____ ate
_____ ate
_____ ite
Hypo _____ ite

What would you call the following ions?

NO_3^- is called nitrate

NO_2^- is called ______________________

SO_3^{2-} is called sulfite

SO_4^{2-} is called ______________________

BrO_3^- is called bromate

BrO^- is called ______________________

4. Complete the following table with the name and formula of the compounds.

	Cl^-	O^{2-}	NO_3^-	PO_4^{3-}
Na^+				
Fe^{2+}				
Fe^{3+}				
Al^{3+}				

5. Give the formula for:

Barium oxide ______________________

Aluminum chloride ______________________

Magnesium phosphate ______________________

Chromium(II) oxide ______________________

Cobalt(II) chloride ______________________

NOMENCLATURE PART II

Name ______________________ Section ______________

1. Below is a list of formulas of ionic compounds. Organize the compounds into sets.

$NaCl$	$Fe(NO_3)_2$	NaI	RbI
KBr	$Fe(NO_3)_3$	Li_3PO_4	BaF_2
$MgCl_2$	KNO_3	Na_2CO_3	$CuSO_4$
$AlCl_3$	$CaBr_2$	CsF	NH_4Cl
$AlBr_3$	NH_4NO_3	$AgCl$	PbI_2

2. Complete the following tables:

Name of the Compound	Formula of the Compound	Ionic or Covalent Compound
	$(NH_4)_2SO_4$	
Calcium chromate		
	C_6H_{14}	
	PCl_5	
Nitric acid		
	$CoCl_3$	

Name of the Compound	Formula of the Compound	Ionic or Covalent Compound
	NH_3	
Potassium phosphate		
	$AgC_2H_3O_2$	
Dichlorine oxide		
	H_2SO_4 (aq)	
Octane		

Name of the Compound	Formula of the Compound	Ionic or Covalent Compound
Sodium sulfide		
Phosphorus pentachloride		
	$Ni_3(PO_4)_2$	
Potassium peroxide		
	HNO_3 (aq)	
	C_7H_{16}	

ATOMIC MASS UNITS AND THE MOL

Name __________ Section __________

1. The atomic mass unit (amu) is related to grams in the following way:

$$1 \text{ amu} = 1.66054 \times 10^{-24} \text{ g}$$

Using this relationship calculate the mass, in grams, of:

a. a gallium atom that has an isotopic mass of 62.96 amu.

b. a molecule of the element bromine.

c. one formula unit of KI.

2. Calculate the mass, in grams, of each of the following:

a. 1000 gallium atoms.

b. 6.023×10^{23} gallium atoms.

c. 6.023×10^{23} molecules of Br_2.

d. 6.023×10^{23} formula units of KI.

3. What is interesting about the answers you calculated in 2b, 2c and 2d with regard to the information in 1a, 1b and 1c respectively?

4. What is the mass of 6.023×10^{23} molecules of C_8H_{18}?

5. Answer each of the following:

   a. How many atoms of hydrogen in one molecule of H_2O?

   b. How many atoms of oxygen in one formula unit of $Pb(NO_3)_2$?

   c. How many atoms of carbon in 1 mol of $C_6H_{12}O_6$?

MOL CALCULATIONS

NAME ______________________ SECTION ______________________

1. Complete the following table:

Formula	*M*, Molar Mass (g/mol)	*m*, Mass of Sample (g)	*n*, Moles of Sample (mol)	*N*, Number of Atoms, Molecules, or Formula Units
CO_2			3.50	
NCl_3				2.65×10^{24} molecules

2. Complete the following table:

Formula	*M*, Molar Mass (g/mol)	*m*, Mass of Sample (g)	*n*, Moles of Sample (mol)	*N*, Number of Atoms, Molecules, or Formula Units
OF_2				8.06×10^{22} molecules
NaI		0.0410		

PERCENT COMPOSITION AND EMPIRICAL FORMULAS

NAME SECTION

1. For the compound $Na_2S_2O_3$:
   a. Determine its molar mass (how many grams of $Na_2S_2O_3$ in 1 mol of $Na_2S_2O_3$).

   b. Calculate the percent (by mass) of the element sodium in $Na_2S_2O_3$.

   c. Calculate the percent (by mass) of the element sulfur in $Na_2S_2O_3$.

   d. Calculate the percent (by mass) of the element oxygen in $Na_2S_2O_3$.

2. A compound is analyzed and found to contain 1.89 g Na, 2.632 g S and 1.975 g O. Calculate the percent composition of sodium, sulfur and oxygen in the compound.

3. A compound is analyzed and found to be 29.11% sodium, 40.50% sulfur and 30.38% oxygen. Determine the empirical formula of this compound.

4. A sample of an unknown compound containing sodium, sulfur and oxygen has a mass of 1.006 g. Analysis shows this sample to contain 0.2928 g of sodium and 0.4074 g of sulfur. Assuming the remaining mass is oxygen, determine the empirical formula of this compound.

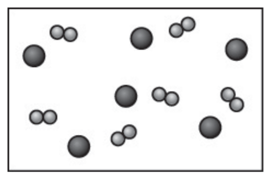
STOICHIOMETRY PART I

Name ______________________ Section ______________________

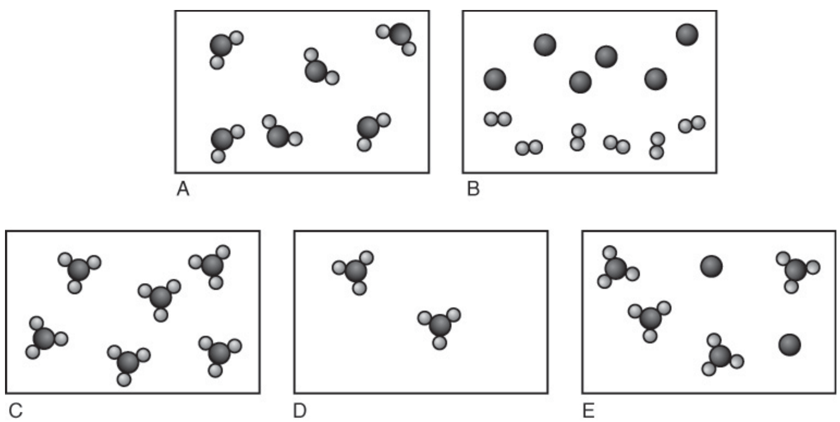
1. The equation for the reaction is:

$$2\ S\ (g) + 3\ O_2\ (g) \rightarrow 2\ SO_3\ (g)$$

Consider a mixture of sulfur atoms and dioxygen molecules in a closed container below:



For each of the following explain why the representation is correct or incorrect.

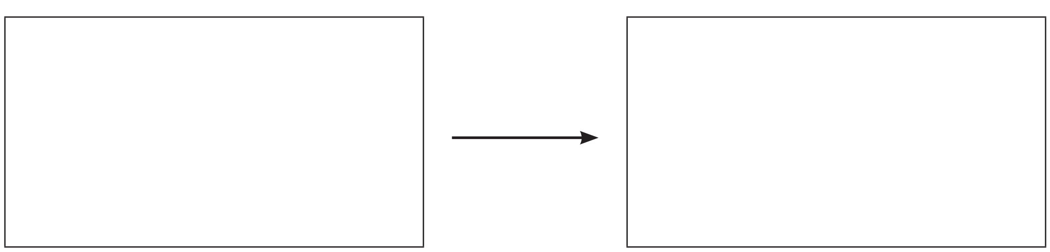


2. The reaction between hydrogen and oxygen to form water is shown below:

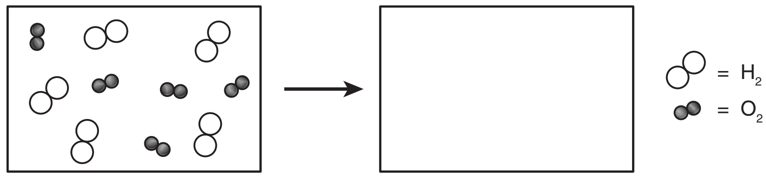
$$2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O\ (g)$$

a. In the container below draw a mixture of the reactants before any reaction has occurred.

b. In the container below draw the mixture after the reaction has occurred as described by the equation above.



c. In the left most container below is a mixture of H_2 and O_2 molecules. In the container on the right, below draw what the contents of the container would be after the reaction takes place.



3. In the combustion reaction

$$2\ C_6H_{14}\,(l) + 19\ O_2\,(g) \rightarrow 12\ CO_2\,(g) + 14\ H_2O\ (g)$$

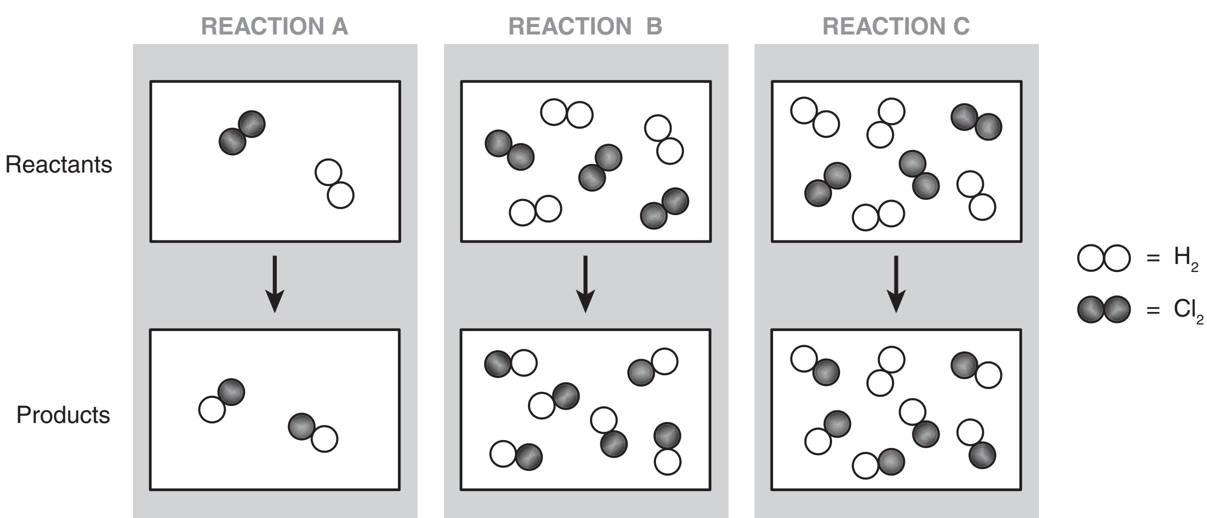
Calculate the number of moles of CO_2 formed when

a. 2.0 moles of C_6H_{14} react with excess O_2.

b. 6.0 moles of O_2 react with excess C_6H_{14}.

c. 38.0 g of H_2O is formed.

4. Consider the three reactions described in the diagrams below.



Which of the above cannot be described by the following chemical equation:

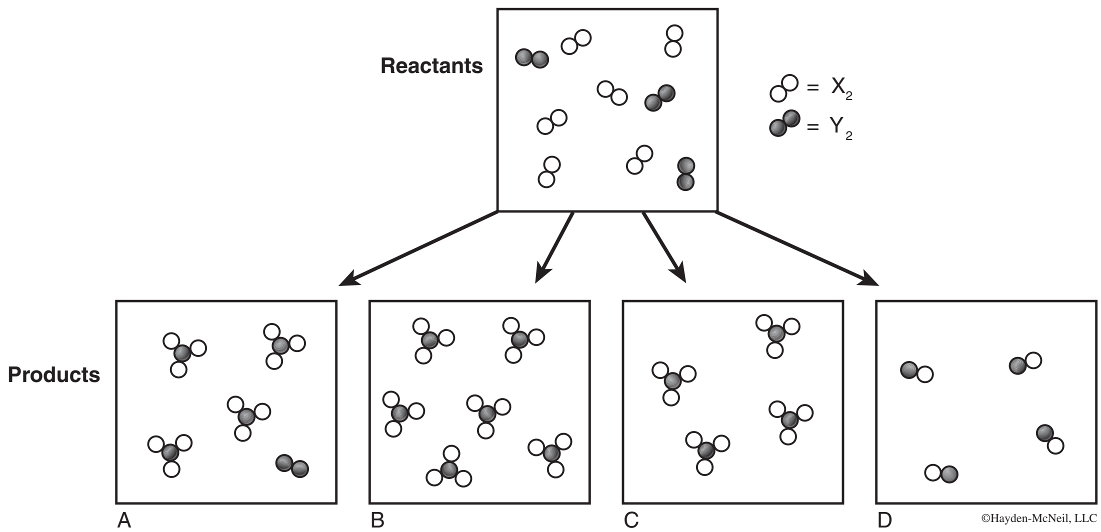
$$H_2 + Cl_2 \rightarrow 2HCl$$

Justify your answer.

LIMITING REAGENTS

Name   Section

1. Analyze the following chemical reaction:



a. Which box best represents what results when X_2 and Y_2 react?

b. Write a balanced equation that describes this reaction in terms of X_2 and Y_2.

c. Is there a limiting reagent? Explain.

2. Which equation, if any, best accounts for the reaction above?

a. $N_2 + 3\ H_2 \rightarrow 2\ NH_3$

b. $H_2 + Cl_2 \rightarrow 2\ HCl$

c. $3\ N_2 + 6\ H_2 \rightarrow 4\ NH_3 + N_2$

d. $6\ H_2 + 3\ Cl_2 \rightarrow 6\ HCl + 3\ H_2$

Student 1: *None, because one nitrogen mixed with three hydrogen only gives us one* NH_3.

Student 2: *c or d, because there was an additional substance left over.*

Student 3: *a, because one molecule of* N_2 *reacts with three molecules of* H_2 *to form two molecules of* NH_3.

Student 4: *a or b, because they are possible results when* X_2 *and* Y_2 *mix.*

Discuss with your partners which, if any, of these statements you agree with. Explain.

3. What else would you need to know in order to decide which reaction is correct?

4. If you were to double the amount of X_2 in the first box in Question 1, what would the result look like?

5. Propane, C_3H_8, is the fuel of choice in a gas barbecue. When propane burns, the reaction that occurs can be described by the following chemical equation:

$$\_\_\ C_3H_8 + \_\_\ O_2 \rightarrow \_\_\ CO_2 + \_\_\ H_2O$$

   a. Balance the chemical equation.

   b. What is the limiting reactant when cooking with a gas grill?

   c. If the grill will not light and you know that you have an ample flow of propane to the burner, what is the limiting reactant?

6. Aspirin is produced by the reaction of salicylic acid and acetic anhydride.

$$\_\_\ \underset{\text{salicylic acid}}{C_7H_6O_3\ (s)} + \_\_\ \underset{\text{acetic anhydride}}{C_4H_6O_3\ (l)} \rightarrow \_\_\ \underset{\text{aspirin}}{C_9H_8O_4\ (s)} + \_\_\ H_2O\ (l)$$

   a. Balance the chemical equation.

   b. If you mix 200 g of each of the reactants, what is the maximum mass of aspirin that can be obtained?

STOICHIOMETRY PART II

Name ____________________ Section ____________________

1. Given an equation

$$2\ C_2H_6\ (g) + 7\ O_2\ (g) \xrightarrow{\Delta} 4\ CO_2\ (g) + 6\ H_2O\ (g)$$

How many mol of CO_2 will be formed by the complete combustion of 6.6 mol C_2H_6?

How many moles of C_2H_6, assuming excess oxygen, are required to form 3.7 mol H_2O?

2. Determine the amount of iodine produced when 145 g of KI react with excess copper(II) chloride.

$$2\ CuCl_2\ (s) + 4\ KI\ (s) \rightarrow 2\ CuI\ (s) + 4\ KCl\ (s) + I_2\ (s)$$

3. List the general steps required to solve any problem in which you are given the mass of each reactant and asked to calculate the mass of one or more products formed as the result of a complete reaction.

4. In the formation reaction

$$2\ SO_2\ (g) + O_2\ (g) \rightarrow 2\ SO_3\ (g)$$

Calculate the number of moles of SO_3 formed when:

a. 2.0 moles of SO_2 are reacted with 5.0 moles of O_2.

b. 6.0 moles of O_2 are reacted with 4.0 moles SO_2.

c. 9.0 moles of O_2 are reacted with 5.0 moles of SO_2.

d. 0.0812 moles of SO_2 react with 0.125 moles of O_2.

e. 20.0 g SO_2 react with 15.0 g of O_2.

CHEMICAL EQUATIONS

NAME ______________________ SECTION ______________________

1. Complete the following table:

Formula	Cation Formula	Anion Formula	Solubility
AgI			
Na_3PO_4			
PbS			
$CsClO_3$			

Solubility Table

Ion	Solubility	Exceptions
NO_3^-	soluble	none
ClO_4^-	soluble	none
Cl^-	soluble	except Ag^+, Hg_2^{2+}, Pb^{2+}*
I^-	soluble	except Ag^+, Hg_2^{2+}, Pb^{2+}
SO_4^{2-}	soluble	except Ca^{2+}, Ba^{2+}, Sr^{2+}, Hg^{2+}, Pb^{2+}, Ag^+
CO_3^{2-}	insoluble	except Group IA and NH_4^+
PO_4^{3-}	insoluble	except Group IA and NH_4^+
OH^-	insoluble	except Group IA, *Ca^{2+}, Ba^{2+}, Sr^{2+}
S^{2-}	insoluble	except Group IA, IIA and NH_4^+
Na^+	soluble	none
NH_4^+	soluble	none
K^+	soluble	none

**slightly soluble*

2. Write the chemical formula(s) of the product(s) and balance the following reactions. Identify all products phases as either (g)as, (l)iquid, (s)olid or (aq)ueous.

   a. $NaOH\ (aq) + Cu(NO_3)_2\ (aq) \rightarrow$

   b. $Na_2SO_4\ (aq) + BaCl_2\ (aq) \rightarrow$

3. Write the ionic and net ionic chemical equations for 2a and 2b.

   Ionic equation:

   Net ionic equation:

   Ionic equation:

   Net ionic equation:

4. Write the chemical formula(s) of the product(s) and balance the following reactions. Identify all products phases as either (g)as, (l)iquid, (s)olid or (aq)ueous.

   a. $NaOH$ (aq) + $HClO_4$ (aq) $\rightarrow$

   b. H_2SO_4 (aq) + KOH (aq) $\rightarrow$

   c. K (s) + H_2O (l) $\rightarrow$

5. Write the ionic and net ionic chemical equations for 4a and 4b.

   Ionic equation:

   Net ionic equation:

   Ionic equation:

   Net ionic equation:

CONCENTRATIONS

NAME _______________ SECTION _______________

1. Write the chemical formula(s) of the product(s) and balance the following reactions. Identify all products phases as either (g)as, (l)iquid, (s)olid or (aq)ueous.

   a. Na_3PO_4 (aq) + $Pb(NO_3)_2$ (aq) →

   b. $Mg(OH)_2$ (aq) + $HClO_4$ (aq) →

   c. $HC_2H_3O_2$ (aq) + NaOH (aq) →

   d. H_2SO_4 (aq) + NH_3 (aq) →

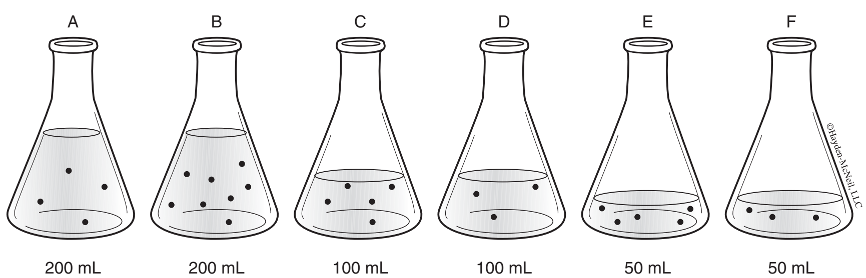
2. Write the ionic and net ionic chemical equations for 1a and 1b.

   Ionic equation:

   Net ionic equation:

   Ionic equation:

   Net ionic equation:

3. 

   a. Which container has the highest concentration? __________

   b. Which container has the lowest concentration? __________

   c. If you pour ½ of A out the concentration will... double? halve? stay the same? Not enough info?

   d. The contents of container A are distributed in the following way into two new empty containers: 50 mL in one container and 150 mL in the other. Draw a picture of the two containers.

   e. If you double the amount of water in E the concentration will be the same as container ______.

4. a. How many grams of magnesium sulfate are required to prepare 250.0 mL of 0.0250 M $MgSO_4$?

   b. Describe how you would prepare this solution.

5. Calculate the molarity of a solution prepared by mixing 9.98 g of NaCl in enough water to make 200.0 mL of solution.

6. What is the concentration of sulfate in a 50.0 mL sample of sodium sulfate if 6.55 mL of 0.0100 M $BaCl_2$ is needed to react with all of the sulfate ion?

Solubility Table

Ion	Solubility	Exceptions
NO_3^-	soluble	none
ClO_4^-	soluble	none
Cl^-	soluble	except Ag^+, Hg_2^{2+}, Pb^{2+}*
I^-	soluble	except Ag^+, Hg_2^{2+}, Pb^{2+}
SO_4^{2-}	soluble	except Ca^{2+}, Ba^{2+}, Sr^{2+}, Hg^{2+}, Pb^{2+}, Ag^+
CO_3^{2-}	insoluble	except Group IA and NH_4^+
PO_4^{3-}	insoluble	except Group IA and NH_4^+
OH^-	insoluble	except Group IA, Ca^{2+}*, Ba^{2+}, Sr^{2+}
S^{2-}	insoluble	except Group IA, IIA and NH_4^+
Na^+	soluble	none
NH_4^+	soluble	none
K^+	soluble	none

**slightly soluble*

SOLUTION STOICHIOMETRY

Name ______________________ Section ______________________

1. a. How many grams of sodium hydroxide are required to prepare 500.0 mL of 0.500 *M* NaOH?

   b. Describe how you would prepare this solution.

2. Calculate the volume of 0.750 *M* KNO_3 that contains 17.0 g of KNO_3.

3. What is the concentration of HCl in a 250.0 mL sample of hydrochloric acid if 15.5 mL of 0.0100 *M* NaOH is needed to react with all of the HCl?

4. Given the reaction

$$2\ Na\ (s) + 2\ H_2O\ (l) \rightarrow 2\ NaOH\ (aq) + H_2\ (g)$$

   a. If a piece of sodium weighing 1.25 grams is added to 450 mL of water, calculate the grams of H_2 produced.

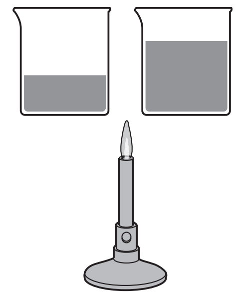
   b. Calculate the concentration of NaOH in the solution after the reaction is complete; assume a negligible volume change.

5. What volume of 0.406 *M* KOH is required to completely react with 18.50 mL of 0.287 *M* H_2SO_4?

MASS, TEMPERATURE AND HEAT

Name　　　　　　　　　　　　　　　　Section

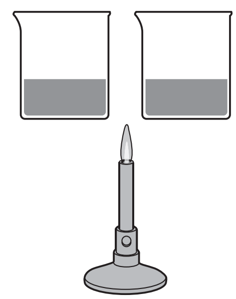
1. Two containers of water are at 20 °C initially. One contains 50 mL and the other 100 mL. They are each heated with the same source of heat for the same amount of time. If the final temperature of the 50 mL sample is 50 °C what would be the final temperature of the 100 mL sample?



   a. 50 °C
   b. 80 °C
   c. 25 °C
   d. 100 °C
   e. 35 °C

   Explain:

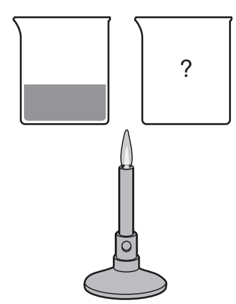
2. Two containers each have 50 mL of water at 20 °C initially. They are each heated with the same source of heat. One is heated for ten minutes and the other for five minutes. If the container that was heated for five minutes has a final temperature 30 °C what would be the final temperature of the other sample?



   a. 35 °C
   b. 40 °C
   c. 60 °C
   d. 25 °C
   e. 30 °C

   Explain:

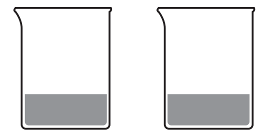
3. Two containers of water are at 20 °C initially. One contains 50 g of water and is heated by a source for a specified time to a final temperature of 30 °C. The second container has an unknown amount of water and is heated with the same source to 30 °C. However, it takes twice as long to get to this final temperature. How much water is in this container?



   a. 100 g
   b. 25 g
   c. 30 g
   d. 50 g
   e. 75 g

   Explain:

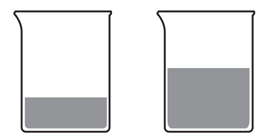
4. 50 mL of water at 80 °C is added to 50 mL of water at 20 °C. What would be the final temperature?



a. 60 °C
b. 40 °C
c. 30 °C
d. 20 °C
e. 50 °C

Explain:

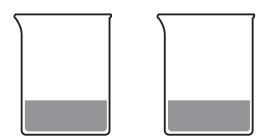
5. 50 mL of water at 80 °C is added to 100 mL of water at 20 °C. What would be the final temperature?



a. 70 °C
b. 40 °C
c. 30 °C
d. 60 °C
e. 50 °C

Explain:

6. 50 g of water at 80 °C is added to 50 g of ethyl alcohol at 20 °C. What would be the approximate final temperature?



a. 60 °C
b. 40 °C
c. 30 °C
d. 20 °C
e. 50 °C

Explain:

CALORIMETRY

Name ______________________________ Section ______________

1. Define each of the quantities in the equation

$$q = m \cdot C_s \cdot \Delta T$$

2. What is the unit on each quantity?

   q ______________

   m ______________

   ΔT ______________

3. a. Rearrange the equation given in Question 1 and solve for C_s.

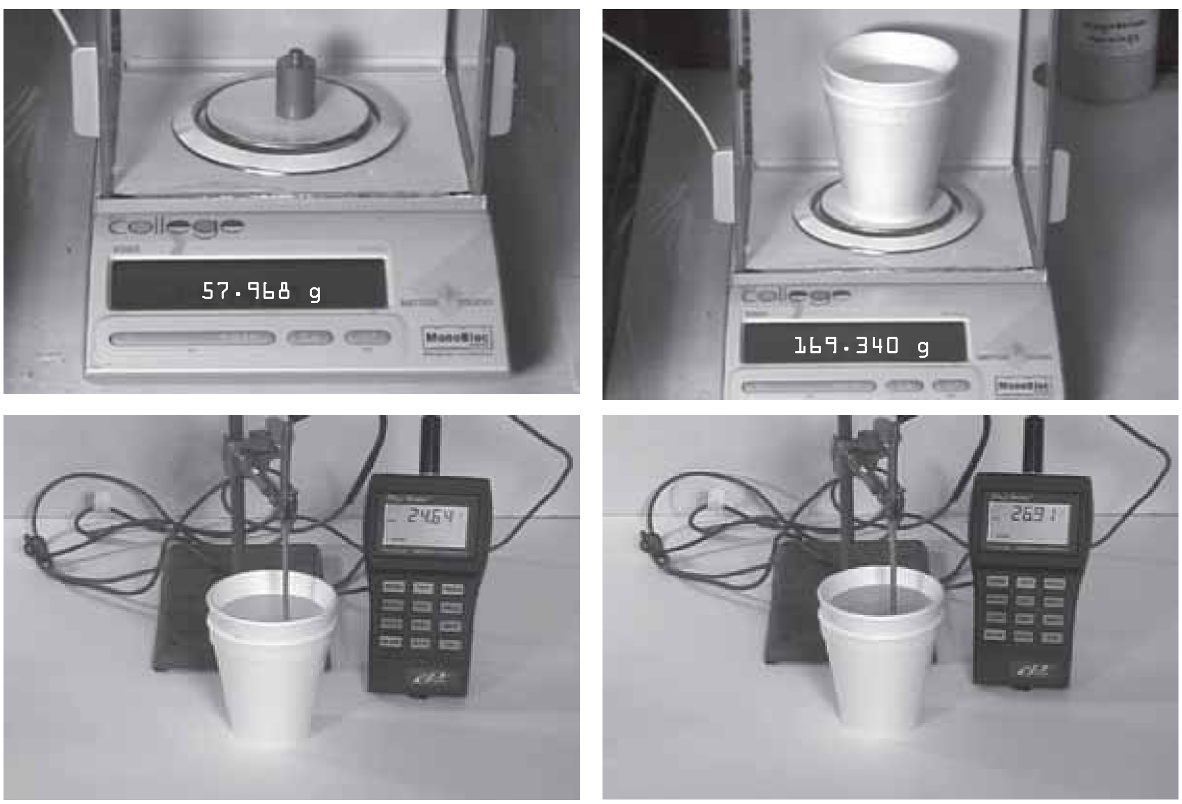
   b. What are the units for C_s?

4. A 175 g sample of water initially at 23.45 °C absorbs some heat. The final temperature of the sample after absorbing the heat is 26.85 °C. Calculate the amount of heat absorbed by the sample of water. (NOTE: The specific heat for water is 4.184 J g^{-1} $°C^{-1}$.)

5. A piece of iron weighing 80.0 g initially at a temperature of 92.6 °C released the same amount of heat to the 175 g sample of water in Question 4. Assume the final temperature of the metal is the same as the final temperature of the water in Question 4. What is the specific heat for iron?

6. The four pictures shown below summarize an experiment. A zinc cylinder of mass 57.968 g was placed in boiling water at 100 °C then plunged into a calorimeter containing 169.340 g of water at 24.64 °C. The temperature of the water and zinc cylinder finally levels off at 26.91 °C. Calculate the specific heat of zinc metal.

Answer:



SOLUTION CALORIMETRY

Name ____________________ Section ____________________

1. A 192 g sample of copper metal is heated to 100 °C in boiling water and then added to 750 g of water at 24.0 °C in a calorimeter. The heat capacity of the calorimeter is 50.0 J $°C^{-1}$. Calculate the final temperature of the water and the copper in the calorimeter. (NOTE: The specific heat of copper is 0.385 J g^{-1} $°C^{-1}$ and for water it is 4.184 J g^{-1} $°C^{-1}$.)

    a. Write the first law heat balance equation for this system.

    b. Solve for the final temperature.

2. When 100. mL of 0.200 *M* CsOH is mixed with 100. mL of 0.200 *M* HCl in a calorimeter the following reaction occurs:

$$CsOH\ (aq) + HCl\ (aq) \rightarrow CsCl\ (aq) + H_2O\ (l)$$

The temperature of both solutions before mixing was 24.30 °C. After mixing, the temperature was 25.68 °C.

    a. What produces the heat in this experiment?

    b. What absorbs the heat in this experiment?

    c. Assuming the density of the resultant solution is 1.00 g mL^{-1}, what is the total mass of the solution?

d. Assuming the specific heat of the resultant solution is 4.18 J g^{-1} $°C^{-1}$, calculate the heat, q, in units of kJ associated (given off or absorbed) with the chemical reaction. Calculate the heat, q, in units of kJ, associated (given off or absorbed) with the 'watery' solution.

e. Calculate the ΔH in units of kJ mol^{-1} of CsOH for the reaction.

3. A 0.692 g sample of glucose, $C_6H_{12}O_6$, is burned in a constant volume, bomb calorimeter. The temperature change is measured at 1.80 °C. The calorimeter contains 1.05 kg of water and the "dry" calorimeter has a heat capacity of 650. J $°C^{-1}$. Calculate the amount heat evolved per mol of glucose.

HESS'S LAW

Name ______________________ Section ______________

1. Predict the product for the following reactions:

   a. NaOH (aq) + HCl (aq) →

   b. NaOH (s) + HCl (aq) →

2. Write the net ionic equation for both reactions in Question 1.

   a.

   b.

3. For each of the following chemical equations predict whether the reaction is exothermic or endothermic.

   a. $2\ C_6H_6O\ (l) + 17O_2\ (g) \rightarrow 12\ CO_2\ (g) + 12\ H_2O\ (l)$

   b. $2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O\ (l)$

   c. $H_2O\ (s) \rightarrow H_2O\ (l)$

   d. $H_2O\ (g) \rightarrow H_2O\ (l)$

4. Calculate Δn (the change in the moles of gaseous substances) for each of the following balanced chemical equations.

   a. $2\ C_6H_6O\ (l) + 17\ O_2\ (g) \rightarrow 12\ CO_2\ (g) + 12\ H_2O\ (l)$

   b. $2\ SO_2\ (g) + O_2\ (g) \rightarrow 2\ SO_3\ (g)$

   c. $N_2\ (g) + O_2\ (g) \rightarrow 2\ NO\ (g)$

   d. $2\ Na\ (s) + Br_2\ (l) \rightarrow 2\ NaBr\ (s)$

5. When 8.50 g of NH_3 are formed, according to the following balanced chemical equation:

$$N_2\ (g) + 3\ H_2\ (g) \rightarrow 2\ NH_3\ (g)$$

23.1 kJ of heat are released.

a. How many kJ of heat are released when 1 mol of N_2 reacts with excess H_2?

b. How many kJ of heat are released when 2 mol of NH_3 are formed?

c. How many kJ of heat are released when 4 mol of N_2 reacts with 4 mol H_2?

6. Use Hess's Law and the following chemical equations:

Chemical Equation	ΔH° (kJ mol^{-1})
$\frac{1}{2} N_2\ (g) + \frac{1}{2} O_2\ (g) \rightarrow NO\ (g)$	30.0
$\frac{1}{2} N_2\ (g) + O_2\ (g) \rightarrow NO_2\ (g)$	46.0

Calculate the ΔH°_{rxn} for the equation

$$2\ N_2\ (g) + 3\ O_2\ (g) \rightarrow 2\ NO\ (g) + 2\ NO_2\ (g)$$

7. Calculate ΔH°_{rxn} for the following reactions:

a. $2\ SO_2\ (g) + O_2\ (g) \rightarrow 2\ SO_3\ (g)$

b. $2\ C_6H_6\ (l) + 15\ O_2\ (g) \rightarrow 12\ CO_2\ (g) + 6\ H_2O\ (l)$

ENTHALPY

Name ______________________ Section ______________

1. The enthalpy for the formation of liquid water is shown below:

$$H_2\ (g) + \frac{1}{2}\ O_2\ (g) \rightarrow H_2O\ (l) \qquad \Delta H^\circ_f = -286\ \text{kJ mol}^{-1}$$

   The enthalpy change for the formation of gaseous water is shown below:

$$H_2\ (g) + \frac{1}{2}\ O_2\ (g) \rightarrow H_2O\ (g) \qquad \Delta H^\circ_f = -242\ \text{kJ mol}^{-1}$$

   Why is the enthalpy change different?

2. Given the enthalpy change for the two reactions below:

$$C\ (s) + \frac{1}{2}\ O_2 (g) \rightarrow CO\ (g) \qquad \Delta H^\circ_f = -111\ \text{kJ mol}^{-1}$$

$$C\ (s) + O_2\ (g) \rightarrow CO_2\ (g) \qquad \Delta H^\circ_f = -394\ \text{kJ mol}^{-1}$$

   Calculate the enthalpy change for the reaction:

$$CO\ (g) + \frac{1}{2}\ O_2\ (g) \rightarrow CO_2\ (g)$$

3. Using the following standard enthalpy of reaction data

$$2\ C\ (s) + 3\ H_2\ (g) \rightarrow C_2H_6\ (g) \qquad \Delta H^\circ_f = -84.68\ \text{kJ mol}^{-1}$$

$$C\ (s) + O_2\ (g) \rightarrow CO_2\ (g) \qquad \Delta H^\circ_f = -394\ \text{kJ mol}^{-1}$$

$$H_2\ (g) + \frac{1}{2}\ O_2\ (g) \rightarrow H_2O\ (l) \qquad \Delta H^\circ_f = -286\ \text{kJ mol}^{-1}$$

   Calculate the heat of reaction for the combustion of 1 mol of ethane (C_2H_6).

4. a. Using standard heats of formation, calculate the ΔH° for the following reaction:

$$C_2H_5OH\ (l) + 3\ O_2\ (g) \rightarrow 2\ CO_2\ (g) + 3\ H_2O\ (l)$$

b. Determine the amount of heat released at constant pressure when 1.00 g of ethanol, C_2H_5OH, is combusted in excess oxygen.

5. Calculate the ΔH° for the following reaction:

$$3\ NO_2\ (g) + H_2O\ (l) \rightarrow 2\ HNO_3\ (aq) + NO\ (g)$$

6. The standard enthalpy of combustion to CO_2 (g) and H_2O (l) at 25 °C of cyclohexane, C_6H_{12} (l), is –3924 kJ/mol. Calculate the standard heat of formation, ΔH°_f, of cyclohexane:

$$C_6H_{12}\ (l) + 9\ O_2\ (g) \rightarrow 6\ CO_2\ (g) + 6\ H_2O\ (l)$$

ELECTROMAGNETIC RADIATION

Name ______________________ Section ______________________

1. a. In the space below, draw a wave that has four wavelengths.

   b. If the distance from one side of the box to the other side is 1 meter, what is the wavelength of the wave you have drawn?

   c. What is the frequency of the wave?

2. Calculate the frequency of light that has a wavelength of 6.7×10^{-5} cm.

3. Describe the difference between the appearances of an emission spectrum and an absorption spectrum for any element.

4. Define quantization. What is a quantum of matter? What is a quantum of light (radiant energy)?

5. Calculate the energy of a photon of orange light with a frequency of 5.0×10^{14} sec^{-1}.

6. Calculate the energy of a mol of photons of orange light with a frequency of 5.0×10^{14} sec^{-1}.

7. Calculate the energy of a photon of light with a wavelength of 425 nm.

8. The energy required to break the oxygen–oxygen bond in O_2 is 496 kJ/mol. Calculate the minimum wavelength of light that can break the oxygen–oxygen bond.

BOHR MODEL

Name ______________________ Section ______________________

1. Draw an energy level diagram for the first 5 energy levels in a hydrogen atom that is based on the Bohr model.

2. Calculate the energy for the n = 1 and the n = 2 level (orbits) for an electron in a hydrogen atom.

3. Describe what can happen when a hydrogen atom absorbs a photon of light, and when a photon of light is emitted from a hydrogen atom.

4. Calculate the energy difference between the n = 1 and the n = 4 levels in a hydrogen atom. What is the energy of a photon that would excite an electron from the n = 1 level to the n = 4 level?

5. Calculate the wavelength of a photon of light that would excite an electron in a hydrogen atom from the n = 1 to the n = 4 level.

6. Calculate the amount of energy required to ionize a hydrogen atom (remove the electron) when the electron is in the n = 1 level.

7. Which condition requires more energy to remove an electron:

   a. when an electron is close to the nucleus, or when an electron is further from the nucleus? Explain.

   b. when the nuclear charge is a +1, or when the nuclear charge is a +5 (assume the electron is the same distance from the nucleus)? Explain.

SHELL MODEL

Name ______________________ Section ______________

1. How many electrons, protons and neutrons in the following atoms?

Atom	Nuclear Charge	Number of Protons	Number of Neutrons	Number of Electrons
H				
He				
Ne				

2. Describe the location of the proton, neutron and electron in an atom such as hydrogen. How do the location of the proton, neutron and electron differ for helium? For neon?

3. Excited atoms emit light energy. How is light energy produced?

4. How would we remove an electron from a hydrogen atom? How would we excite an electron in a hydrogen atom?

5. Write a chemical equation that describes the first ionization energy for:

   a. a hydrogen atom.

   b. a helium atom.

   c. a neon atom.

6. Below are the first ionization energies for elements Z = 1 to Z = 19.

Symbol	Z	IE (kJ mol^{-1})
H	1	1312
He	2	2372
Li	3	520
Be	4	899
B	5	801
C	6	1086
N	7	1402
O	8	1314
F	9	1681
Ne	10	2081

Symbol	Z	IE (kJ mol^{-1})
Na	11	496
Mg	12	738
Al	13	578
Si	14	786
P	15	1012
S	16	1000
Cl	17	1251
Ar	18	1520
K	19	419

What patterns do you see in the data above?

7. Diagram each of the following atoms using the shell model.

   a. hydrogen

   b. helium

   c. lithium

   d. nitrogen

   e. sodium

   f. chlorine

SHIELDING

Name ____________________ Section ____________________

1. How many electrons, protons and neutrons in the following atoms?

Atom	Nuclear Charge	Number of Protons	Number of Neutrons	Number of Electrons
H				
He				
Ne				

2. How would we remove an electron from a hydrogen atom? How would we excite an electron in a hydrogen atom?

3. Write a chemical equation that describes the first ionization energy for:

   a. a hydrogen atom.

   b. a helium atom.

   c. a neon atom.

4. For each of the following atoms, what "core" charge are the electrons in the outer shell attracted by?
   a. hydrogen
   b. lithium
   c. beryllium
   d. fluorine
   e. sulfur
5. What does the term "shield" mean when describing the attraction experienced by an electron in an outer shell?

6. Complete the following table:

Element	Nuclear Charge	Total Number of Electrons	Number of Inner Core Electrons	Number of Valence Electrons	Effective Nuclear Charge
Hydrogen					
Lithium					
Beryllium					
Boron					
Carbon					
Nitrogen					
Oxygen					
Fluorine					
Sulfur					
Potassium					
Bromine					

ELECTRON CONFIGURATION PART I

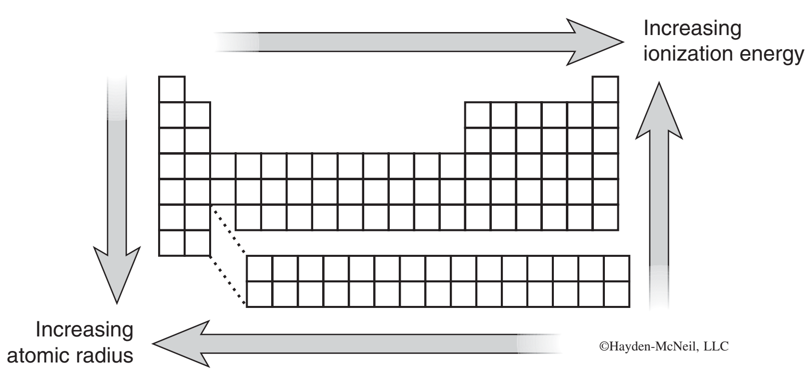
NAME ______________________ SECTION ______________

1. Write the *electronic configuration* for the *valence electrons* for each of the following elements and ions and their *Lewis dot structure*:

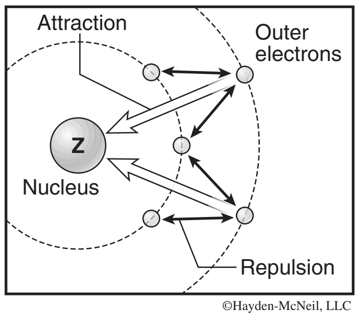
Period	Group IA		Group IIA		Group IIIA		Group VIA		Group VIIA	
	Atom	Ion	Atom	Ion	Atom	Ion	Atom	Ion	Atom	Ion
2	Li	Li^+	Be	Be^{2+}	B	B^{3+}	O	O^{2-}	F	F^-
3	Na	Na^+	Mg	Mg^{2+}	Al	Al^{3+}	S	S^{2-}	Cl	Cl^-
4	K	K^+	Ca	Ca^{2+}	Ga	Ga^{3+}	Se	Se^{2-}	Br	Br^-

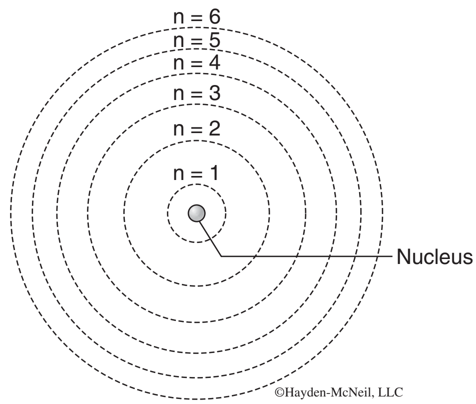
If you want to ***learn*** *and not just memorize rules, it is CRITICAL that you* ***don't use*** *your notes for the rest of this problem.*

2. The periodic table below shows the periodic trends for the atomic radius and the ionization energy (IE).



Based on the table that you built in Question 1, the periodic trends shown above and the two pictures below explain:





a. why the radii of atoms decrease across a period.

b. why the radii of atoms increase down a group.

c. why the ionization energy increases across a period.

d. why the ionization energy decreases down a group.

3. The **radius of a cation** (positive ion) is always **smaller** than that of the atom from which it is derived. On the other hand, the **radius of an anion** (negative ion) is always **bigger** than that of the atom from which it is derived.

   Using the information provided above, explain why.

4. Write the electronic configuration of the following elements and ions (Watch for the exceptions!):

Cr ____________________	Cr^{3+} ____________________
Fe ____________________	Fe^{2+} ____________________
Ne ____________________	Fe^{3+} ____________________
Cu ____________________	Cu^{+} ____________________
C ____________________	Cu^{2+} ____________________

ELECTRON CONFIGURATION PART II

NAME ______________________ SECTION ______________

1. Write the complete electron configuration for:
   a. F
   b. Si
   c. Zn
   d. Er

2. The maximum number of electrons in:
   a. the 2nd shell
   b. a d subshell
   c. a p orbital
   d. 3 p subshell

3. Draw an orbital diagram for:
   a. nitrogen
   b. aluminum
   c. chromium

4. What does the term "shield" mean when describing the attraction experienced by an electron in an outer shell?

5. Complete the following table:

Element	Total Number of Electrons	Electron Configuration
Hydrogen		
Lithium		
Beryllium		
Boron		
Carbon		
Nitrogen		
Oxygen		
Fluorine		
Sulfur		
Potassium		
Bromine		

IONIZATION ENERGY

Name ______________________ Section ______________________

1. Complete the following table:

Element	Nuclear Charge	Complete Electron Configura-tion	Total Number of Electrons	Number of Inner Core Electrons	Number of Valence Electrons	Effective Nuclear Charge
Hydrogen						
Lithium						
Beryllium						
Boron						
Carbon						
Nitrogen						
Oxygen						
Fluorine						
Sulfur						
Potassium						
Bromine						

2. What does the term "shield" mean when describing the attraction experienced by an electron in an outer shell?

3. Why is the first ionization energy for nitrogen greater than the first ionization energy for lithium?

4. Calculate the effective nuclear charge experienced by an electron in the 2nd shell in a bromine atom.

5. Why is the third ionization energy for magnesium so much greater than the second ionization energy?

6. Explain the basis for the rule "the atomic radius decreases going across a period."

PREDICTING IONIZATION ENERGIES

Name ______________________ Section ______________

The following table has ionization energies for the third row of the periodic table. The energies listed are in units of kJ/mol and represent the amounts of energy necessary to remove the first electron (I_1), the second electron (I_2), and so on for each atom. Some of the entries are left blank. Estimate what approximate value should be entered into each of the lettered boxes. Take into account the trends in the periodic table. But be careful! Take into account the nature of the electron that must be removed; what energy level and what orbital each electron occupies.

	Na	Mg	Al	Si	P	S	Cl	Ar
I_1	492	733	a	781	1013	b	1254	1524
I_2	4562	1447	1813	c	1900	2257	2296	2662
I_3	d	e	f	3231	g	3376	3848	3945
I_4	9539	10542	11574	4350	4958	4562	5160	5768
I_5	13349	13619	14853	16107	6269	6993	6539	7234
I_6	16599	17988	18326	19772	h	8488	9327	8806

Explain your reasons for the values you predicted for each box.

IONIC RADII AND IONIC BONDS

Name ____________________ Section ____________________

1. Complete the following table:

Element	Nuclear Charge	Complete Electron Configura-tion	Total Number of Electrons	Number of Inner Core Electrons	Number of Valence Electrons	Effective Nuclear Charge
Na						
Cl						
Na^{+}						
Cl^{-}						
Mg						
Mg^{+}						
Mg^{2+}						
S						
S^{2-}						

2. Why is the 2nd ionization energy in Na significantly greater than the first ionization energy for Na? Explain in terms of ENC.

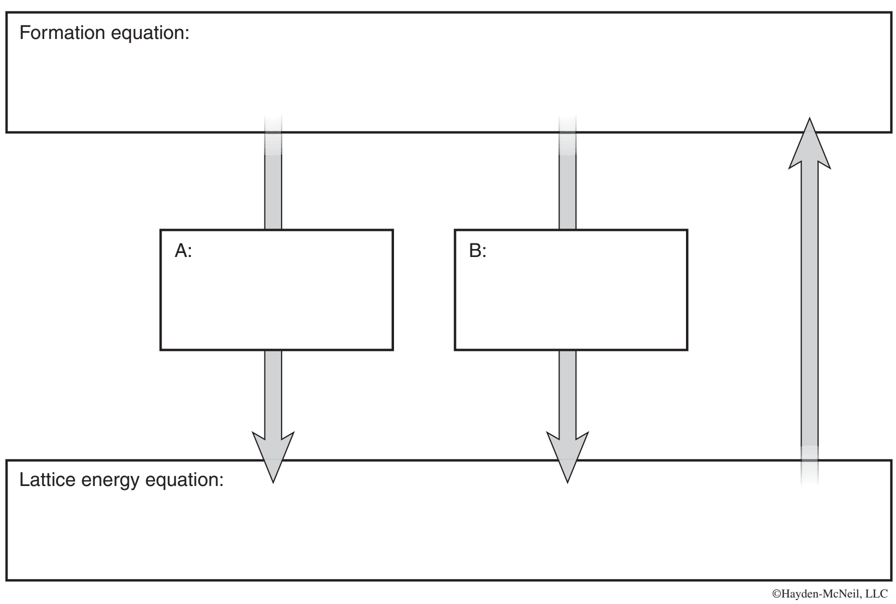
3. Why is the 2nd ionization energy in Mg a little larger compared to the first ionization energy for Mg? Explain in terms of ENC.

4. Which is larger, a sulfur atom or a sulfide ion? Explain in terms of ENC.

5. Write the chemical equation (lattice energy) that is used to determine the strength of an ionic bond in an ionic compound such as NaBr.

6. Write the chemical equation that describes the formation reaction for NaBr.

7. In the diagram below, first write the formation equation in the designated space, then write the lattice energy equation (exothermic form). Complete box A and box B with a chemical species that converts the reactant in the formation equation to the reactant in the lattice energy equation.



8. Write the six chemical equations and indicate how Hess's Law can be used to calculate the lattice energy (U) for the ionic compound NaBr.

COVALENT BONDS AND LEWIS STRUCTURES

NAME ______________________ SECTION ______________

1. Draw an orbital diagram for the valence electrons in:

   a. C

   b. N

   c. F

   d. H

2. Draw the complete Lewis structure for:

   a. C

   b. N

   c. F

   d. H

3. Draw the complete Lewis structure for:

a. HF

b. H_2O

c. NH_3

d. CCl_4

e. ClO_2^-

f. $HClO_2$

g. CH_4

h. C_2H_6

i. C_5H_{12}

k. CO_2

l. C_2H_4

m. O_3

RESONANCE STRUCTURES AND FORMAL CHARGE

Name

Section

1. Draw the complete Lewis structure for:

   a. H_2SO_4

   b. O_3

   c. NO_2^-

   d. CO_3^{2-}

2. Draw the complete Lewis structure for:

   a. PCl_3

   b. $COCl_2$

   c. SO_3^{2-}

   d. NCS^-

3. Determine the formal charge on each atom in Question 2.

   a.

   b.

   c.

   d.

BOND ENERGIES

Name ______________________ Section ______________________

1. Given the information in the table below:

Bond Lengths and Bond Energies

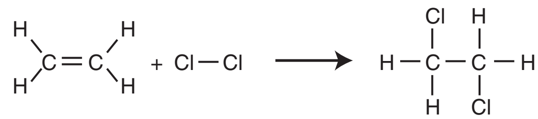
	Bond Length (nm)	Bond Energy (kJ/mol)
H–H	0.074	435
H–Cl	0.127	431
Cl–Cl	0.198	243
H–C	0.109	414
C–Cl	0.177	328
C–C	0.154	331
C=C	0.134	590
C≡C	0.120	812

	Bond Length (nm)	Bond Energy (kJ/mol)
C–O	0.143	326
C=O	0.120	803
C≡O	0.113	1075
N–N	0.145	159
N=N	0.125	473
N≡N	0.110	941
O_2	0.121	495
H–O	0.096	463

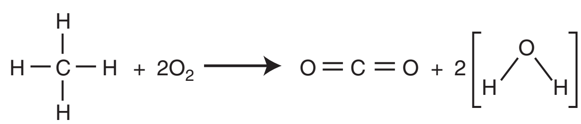
Explain the observed relationship between bond length and bond energy in the three examples of carbon–carbon bonds and in the three examples of carbon–oxygen bonds. Which is stronger and why?

Compare the bond strengths in a dihydrogen molecule and a chlorine molecule. Which is stronger and why?

2. Using bond energies, calculate ΔH° for the reaction



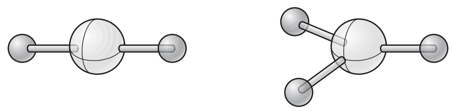
3. Using bond energies, calculate ΔH° for the reaction



BOND ANGLES

Name ______________________ Section ______________________

1. a. Estimate the O–C–O bond angle in the following molecules, in which the central atom is carbon and the terminal atoms are oxygen.



   b. Write the formula for each species depicted above.

2. a. Draw the Lewis electron dot structure for CCl_4 and identify all the bonding pairs and nonbonding pairs of electrons on the central atom.

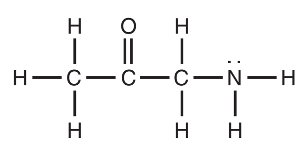
   b. What is the Cl–C–Cl bond angle?

3. Draw the Lewis electron dot structure for NF_3 and identify all the bonding pairs and nonbonding pairs of electrons.

4. Complete the following table:

Sketch Geometry	Compound	Number of Bonding Groups on Central Atom	Number of Non-bonding Pairs on Central Atom	Name of the Molecular Geometry	Bond Angle(s)
	SO_3				
	SO_3^{2-}				
	NO_2^-				
	I_3^-				
	ICl_3				

5. Indicate the geometry about each of the "central atoms" in the molecule shown below.



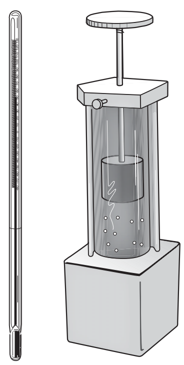
6. Indicate the geometry about each of the "central atoms" in the molecule CH_3CH_2OH.

GAS LAWS

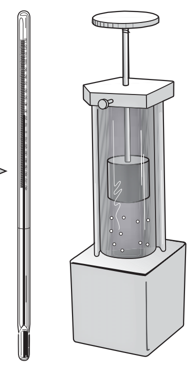
Name ______________________ Section ______________

1. For pairs 1–3 fill in the blanks (calculate the value of the variables and identify which law applies), circle the correct relationship, and draw diagrams for Question 3.

1)



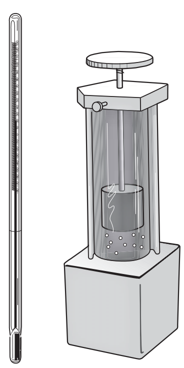
Initial:
P = 5 atm
T = 50 °C
V = 10 L



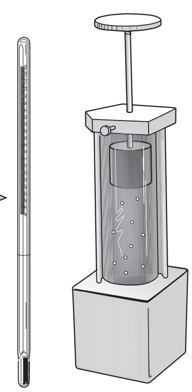
Final:
P = ______
T = 25 °C
V = 10 L
Direct or inverse relationship?

Law: ______________________

2)



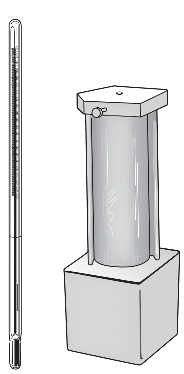
Initial:
P = 10 atm
T = 20 °C
V = 5 L



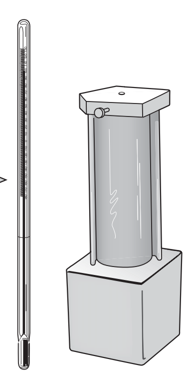
Final:
P = 10 atm
T = ______
V = 20 L
Direct or inverse relationship?

Law: ______________________

3)



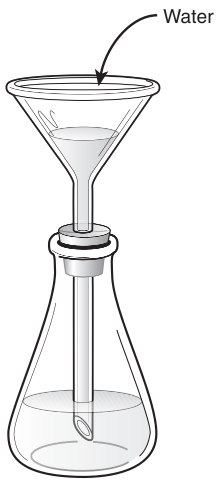
Initial:
P = 10 atm
T = 100 °C
V = 2 L



Final:
P = 20 atm
T = 100 °C
V = ______
Direct or inverse relationship?

Law: ______________________

2. In the figure below, an Erlenmeyer flask is tightly closed by a rubber stopper containing a funnel. If we pour water into the funnel slowly, the water easily enters the Erlenmeyer flask. However, when the water level inside the flask reaches the foot of the funnel, it is no longer easy to add water. **Can you explain in your own words why this happens?**



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3. The label of an aerosol can below says "Pressurized container. Protect against sunlight and do not expose to temperature exceeding 50 °C." **Explain the reasons for this warning.**

GAS LAWS PART II

Name Section

1. Distinguish between the gas, liquid and solid phase by listing the unique properties of each that are not shared by the others.

   Gas:

   Liquid:

   Solid:

2. When an aerosol can is full at 25 °C, the internal pressure is 2.50 atm. What is the new internal pressure at 1000 °C?

3. If 1.00 moles of an ideal gas at 1.00 atm and 273 K (STP) occupies a volume of 22.4 L, calculate the value and determine the units for R.

4. What pressure is required to confine 0.460 mol of an ideal gas at 33.0 °C in a volume of 9.50 L?

5. What is the volume of a bulb that contains 3.56 g of nitrogen gas at 25.0 °C and 3.50 atm?

6. Calculate the density of oxygen gas at 1.00 atmosphere and 0.00 °C.

GAS LAWS PART III

Name ______________________ Section ______________

1. Calculate the volume of a sample of helium at –33.0 °C and 1.23 atm if it occupies a volume of 2.34 L at 54.5 °C and 1026 mmHg.

2. A 0.751 mol sample of an ideal gas occupies a 10.0 liter flask at 27.0 °C and 1.85 atm. If 0.257 mol of the gas are removed from the container, calculate the new pressure. (Assume the temperature remains constant.)

3. What is the volume of a bulb that contains 3.56 g of nitrogen gas at 25.0 °C and 3.50 atm?

4. Calculate the density of SF_6 at 1.00 atm and 0.00 °C.

5. Consider the reaction

$$2\ NaOH\ (s) + CO_2\ (g) \rightarrow Na_2CO_3\ (s) + H_2O\ (l)$$

which is a chemical means, although not economically viable, of removing CO_2 from the atmosphere. How many liters of CO_2 at 25.0 °C and 745 mmHg can be removed by 1.00 kg of NaOH?

6. Calculate the total pressure in a 10.0 liter flask at 21 °C which contains 4.00 g H_2, 12.0 g O_2, and 8.00 g He.

7. A common laboratory preparation of O_2 involved the decomposition of hydrogen peroxide, H_2O_2, according to the equation:

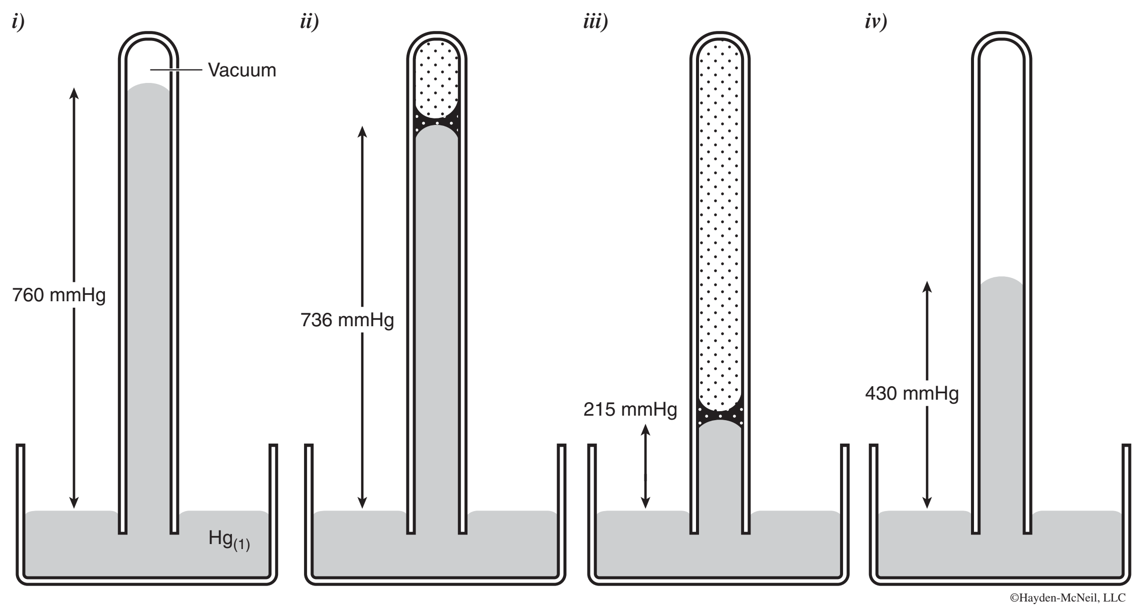
$$2\ H_2O_2\ (aq) \rightarrow 2\ H_2O\ (l) + O_2\ (g)$$

If 240 mL of O_2 at 23 °C and at 0.965 atm pressure are collected over a sample of water at the same temperature, determine the number of moles of O_2 obtained in the reaction.

VAPOR PRESSURE

NAME SECTION

1. Consider the sketches of four barometers. Barometer i shows the measurement of atmospheric pressure. Barometer ii depicts the situation of a sample of water having been injected into the tube. Barometer iii and iv depict samples of diethyl ether having been injected into the tubes. All four barometers are at the same temperature.



   a. Why does the height of the mercury column change when liquids are injected?

   b. What is the equilibrium vapor pressure of diethyl ether?

   c. What is the pressure of the diethyl ether vapor in barometer iv?

d. Based on your answers in b and c, what mass of diethyl ether, compared to that in barometer iii, was originally injected into barometer iv? (Note: Answer *more than*, *less than*, or *the same amount as*.)

e. Complete barometer iv by carefully sketching in the space above the mercury level in the tube symbols (dots) which correctly represent the phase(s) present.

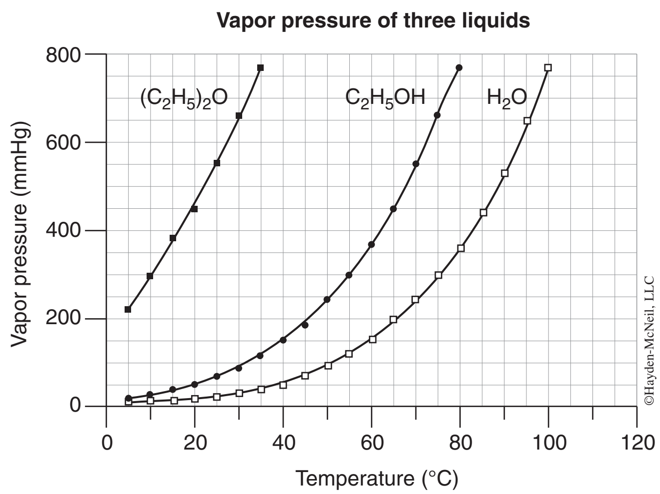
f. Using your answers for c through e, explain what happened when the sample of diethyl ether was originally injected into barometer iv.

VAPOR PRESSURE AND TEMPERATURE

NAME

SECTION

1. Using the information on the graph below, explain how a change in temperature of a liquid effects its vapor pressure.



2. Write the Clausius-Clapeyron equation in the space below and define each term.

3. Given that the vapor pressure of ammonia is 164 mmHg at –56 °C, calculate the vapor pressure at –45 °C. ΔH°_{vap} = 28.0 kJ/mol.

4. Calculate the normal boiling point of ammonia knowing the vapor pressure at –38 °C is 538 mmHg. ΔH°_{vap} = 28.0 kJ/mol.

5. Using the vapor pressure data for acetic acid, $CH_3COOH(l)$,

t (°C)	P_v (mmHg)
10.0	6.00
20.0	11.6
30.0	21.3
40.0	37.3
50.0	63.7

complete the table below and plot ln (P_v) vs. 1/T (K) on your calculator. Use your graph to estimate the heat of vaporization of acetic acid. (Note: ln is the natural log function.)

T (°C)	T (K)	1/T (K)	P_v (mmHg)	ln (P_v)
10.0	283		6.00	
20.0	293		11.6	
30.0	303		21.3	
40.0	313		37.3	
50.0	323		63.7	

INTERMOLECULAR ATTRACTIVE FORCES

Name _______________ Section _______________

1. Sketch the orientations of molecules and/or ions involved in the following intermolecular attractive forces. Include at least one specific example where each attractive force is important. For each one, tell what causes the force and describe its strength relative to the others.

   a. ion–dipole forces

   b. dipole–dipole forces

   c. London dispersion forces

   d. hydrogen-bonding forces

2. Complete the following table:

System	Primary Intermolecular Force	Sketch of Interaction Between Particles
CH_2Cl_2 (l)		
NH_3 (l)		
SO_2 (l)		
KBr (s)		
I_2 (s)		
NaCl (aq)		
CH_3CH_2OH (aq)		

SOLIDS

Name

Section

1. Describe the difference between atomic, molecular, ionic and covalent solids. Include comparisons of physical properties, such as melting points, as well as types of intermolecular forces present.

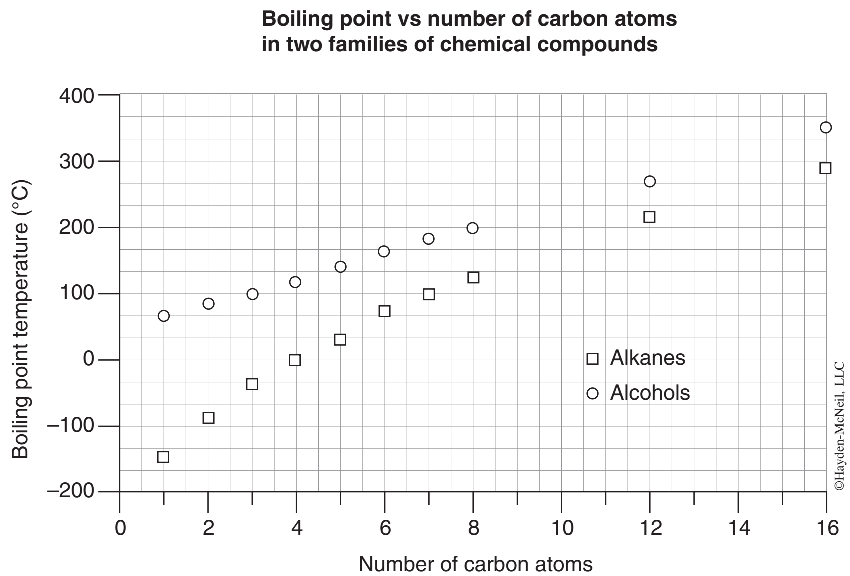
2. Define the term "unit cell" and sketch the unit cell for simple cubic, body-centered cubic, and face-centered cubic crystals.

3. Complete the following table:

Unit Cell	Number of Corner Atoms	Number of Edge Atoms	Number of Face Atoms	Number of Atoms Entirely Within the Cell	Total Number of Atoms in Unit Cell
Simple cubic					
Body-centered cubic					
Face-centered cubic					

Name ______________________ Section ______________

Examine the following graph:



The graph above shows the relationships between the boiling points and the number of carbon atoms of two families (classes) of chemical compounds, alkanes and alcohols. An alkane is a compound that contains only carbon and hydrogen atoms in its molecules. An alcohol is a compound that contains carbon and hydrogen atoms, and one oxygen atom in each of its molecules.

1. What is the relationship between the boiling points and the number of carbon atoms for each of the families of compounds, and how do you explain this relationship?

2. What is the relationship between the two families of compounds and how do you explain this relationship?

3. Predict the boiling point of a 10-carbon alkane, a 10-carbon alcohol, a 20-carbon alkane, and a 20-carbon alcohol.

4. The two lines seem to get closer together as the number of carbon atoms increases. Explain why this happens.

BONDING IN ORGANIC COMPOUNDS

Name ____________________ Section ____________________

1. Draw the complete Lewis structure for the molecule C_2H_6. Use your structure to answer the following:
   a. What kind of hybrid orbitals are used by the carbon atoms?
   b. What is the atomic orbital on each hydrogen that overlaps with the hybrid orbital on carbon?
   c. What are the bond angles in this molecule?
   d. How many sigma and pi bonds are there in this molecule?
   e. What is the shape of the molecule around a central atom?
   f. Is the molecule polar or nonpolar?

2. Draw the complete Lewis structure for the molecule C_2H_4. Use your structure to answer the following:
   a. What kind of hybrid orbitals are used by the carbon atoms?
   b. What are the bond angles in this molecule?
   c. How many sigma and pi bonds are there in this molecule?
   d. What is the shape of the molecule around a central atom?
   e. Is the molecule polar or nonpolar?

3. Draw the complete Lewis structure for the molecule C_2H_2. Use your structure to answer the following:

   a. What kind of hybrid orbitals are used by the carbon atoms?

   b. What are the bond angles in this molecule?

   c. How many sigma and pi bonds are there in this molecule?

   d. What is the shape of the molecule around a central atom?

   e. Is the molecule polar or nonpolar?

4. Draw the complete Lewis structure for the molecule $(CH_3)_2CH(CH_2)_2CHCHCH_2C(CH_3)_3$ and identify the hybridization on each carbon atom in the structure.

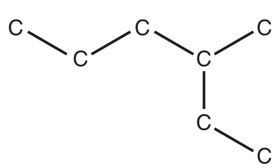
5. When any of the compounds in Questions 1–3 are burned in oxygen, O_2, what are the products of the chemical reaction?

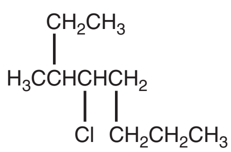
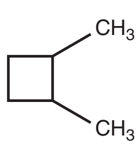
   Is this reaction endothermic or exothermic?

ORGANIC NOMENCLATURE AND FUNCTIONAL GROUPS

Name ______________________ Section ______________________

1. Using organic nomenclature rules, name or draw a complete structure for each of the following compounds.

a. $CH_3CH_2CH_2CH_3$	
b.	3,3-dimethylpentane
c. $CH_3C(CH_3)_2C(CH_3)_2C(CH_3)_2CH_3$	
d. 	
e.	4,4-dimethyl-cis-2-hexene

<table>
<tr><td>f.</td><td>2-bromo-1-chloro-3-methylbutane</td></tr>
<tr><td>g.</td><td></td></tr>
<tr><td>h. 
</td><td></td></tr>
<tr><td>i.</td><td>3-heptyne</td></tr>
<tr><td>j.</td><td>1,2-dimethyl-3-chlorocyclopentane</td></tr>
<tr><td>k. 
</td><td></td></tr>
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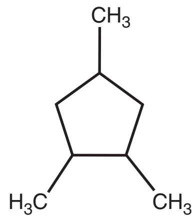
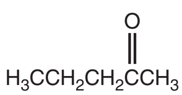
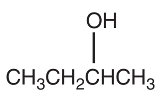
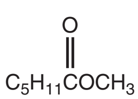
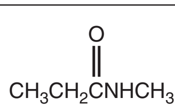
l. 	

2. Circle and name each of the functional groups in the following compounds.

a. 	
b. 	
c. $CH_3CH_2OCH_3$	
d. CH_3COCH_3	
e. 	
f. CH_2CHCH_3	
g. 	

ISOMERS

Name

Section

Molecules that have different numbers and kinds of atoms have different physical and chemical properties. It is also the case that some molecules that have the same numbers and kind of atoms can also have different physical and chemical properties. This is because these molecules either have the atoms connected together with different other atoms, or because the atoms are connected to the same atoms but their three-dimensional arrangement is structurally different. Such molecules are said to be isomers. The ultimate test for isomerism is for two molecules to be nonsuperimposable. That is, when the two molecules are held close to each other, the atoms don't line up in a one-to-one correspondence. If they do, the molecules are identical. This test can sometimes be tricky to apply because atoms can be freely rotated around single bonds (but not around double bonds) to rearrange the molecule.

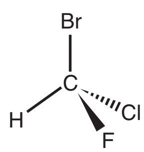
1. Generate all of the possible isomers of C_6H_{14}.

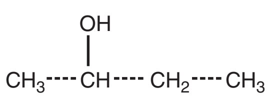
2. Generate all of the possible isomers of $C_5H_{12}O$.

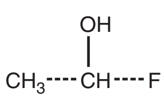
3. Generate all of the possible isomers of $C_5H_{10}O$.

4. Draw the six isomers of C_4H_8.

5. Optical isomers are nonsuperimposable mirror images of each other. Which of the following molecules exhibit optical isomerism? Draw the optical isomers of those molecules using three-dimensional perspective drawings.







6. From the above examples, state a rule for identifying a molecule that exhibits optical isomerism.

Computer Lab Activities

MoLEs

Introduction to MoLEs Activities

Stoichiometry

- Mass and Particle Relationships
- Mass and Particle Systems and Research Statements

Gas Laws

- Gas Pressure and Volume Relationships
- Gas Pressure and Temperature Relationships
- Gas Systems and Research Statements

Molecular Modeling

Introduction to Molecular Modeling

- I. VSEPR
- II. Carbon Compounds
- III. Periodic Trends
- IV. Solids
- V. Isomerism
- VI. Polarity

Laboratory Simulations

Introduction to Laboratory Simulations

Mass Relationships

- Heating a Hydrate
- Burning a Hydrocarbon I
- Burning a Hydrocarbon II

Thermochemistry

- Heats of Solution
- Heat Transfer

Atomic Structure

- Electronic Configuration

Gas Behavior

- Pressure–Volume Relationships
- Volume–Temperature Relationships
- Effusion

MoLEs

Introduction to MoLEs Activities—Computer Simulations*

Molecular Level Experiments (MoLEs) are chemistry laboratory experiments based on computer simulations. There are two types of simulation programs that can be used in these activities: Particulate Simulations and Graphic Simulations.

To begin an activity you must be able to log on to the Internet using Internet Explorer (Microsoft) 4.5 or higher or Safari with OS X for Macs.

If the IE browser window shows a boxed section with a small "X" icon in the upper left corner, this means the simulation cannot load due to the missing Java Runtime Environment (JRE) for IE. If there is any problem with the simulation window, you will need the more current version of the Java Runtime Environment for Windows. To get the latest version for your hardware, go to java.sun.com. In the right frame, find the section titled Popular Downloads. In this section, click on Java SE. In the new page that is loaded, scroll down until you find Java Runtime Environment (JRE) 6 Update 6 (as new updates appear, this may change). Click on the Download button. In the next window, select your platform from the drop-down menu, click on the checkbox that you agree with the licensing agreement, then click the Continue button. Click on the Windows Online Installation and follow the instructions. (It is that easy.) This will download to your computer and automatically accessorize IE so it will open the simulations.

* Software used in these activities were developed and programmed by Kirk Haines, John Gelder, and Michael Abraham.
 Project supported by NSF-CCLI-EMD #0127563

Particulate Simulations

Once the browser is running, type the following address into the location-input line of your browser:

http://introchem.chem.okstate.edu/DCICLA/Sample.htm

This should load a sample Particulate Simulation. Once you have the simulation running, your screen should look similar to what is shown in Figure 1 below.

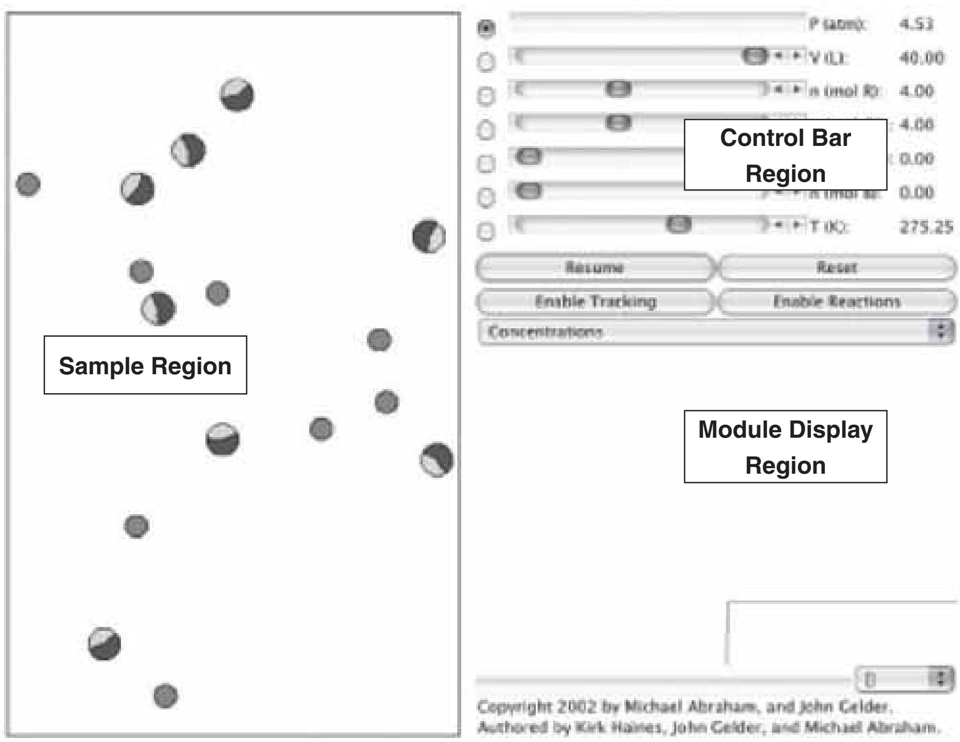


Figure 1.

Although the details of the screen you will see will vary with different MoLE activities, all Particulate Simulations have three important regions. The Sample Region has the most activity. It is a container with different kinds of particles. To explore the behavior of the sample you can change the variables located in the Control Bar Region. The Control Bar Region has scrollbars that allow you to change the variables of the experiment. There are scrollbars for pressure (in units of atmospheres), for volume (in units of liters), for the amount of each substance that is active in the Sample Region (in moles), and for temperature (in units of Kelvins). The concentration of each substance can be calculated by dividing the number of moles by the volume of the container. To the left of each scrollbar is a radio button. When selected, that particular variable (called the dependent variable) is calculated based on the value of the other variables. In the default mode the pressure scrollbar's radio button is selected so the pressure of the sample is varied.

As a simple exploration, try moving each of the scrollbars and observe the effect on the sample. These effects will be address in more detail in each experiment. You can click the mouse on the Reset button located below the temperature scrollbar to return to the original conditions. The Pause button will suspend the motion in the gas sample while the Enable Tracking button will turn the red tracking line on and off.

The region below the Control Bar Region is the Module Display Region. This region allows the data in the other regions to be represented graphically or in tables in several ways depending on the particular activity you are doing. These might include simple graphs comparing variables, concentration strip charts showing concentrations vs. time, energy reaction profiles showing the relative energies of reactants and products of a chemical reaction, and a replay feature that allows you to replay and slow down a portion of the particulate interactions showing in the Sample Region. To utilize these different functions, use the pull-down menu located below the temperature scrollbar.

The Concentrations option shows the relative concentrations and changes in concentration vs. time for each substance studied in the simulation. Manipulate the amounts using the Control Bars to see how the strip chart is affected. These effects will be addressed in more detail in experiments that utilize this function. You can click on the Reset button located below the temperature scrollbar to return to the original conditions.

The Replay option (see Figure 2) allows you to slow down the motion in the Sample Region and to replay portions of the reaction sequence. You can click on the Pause Button and, using the forward or reverse arrows on the time index function, view the motion of the particles a step at a time. These effects will be addressed in more detail in experiments that utilize this function. You can click the mouse on the Reset button located below the temperature scrollbar to return to the original conditions.

Figure 2.

The Kinetics option allows you to record quantitative information being generated by the strip chart. Three columns of data are generated: time, amount, and instantaneous rate. These data are generated by specifying the compound you want to follow and then clicking on the Get Data button. This can be done as many times during the reaction as you want. These effects will be addressed in more detail in experiments that utilize this function.

The Reaction Viewer shows the reaction profile for a chemical reaction as it proceeds from reactants to products. These effects will be addressed in more detail in experiments that utilize this function.

The Relations option reveals an xy graph with a dropdown menu on each axis. Selecting the dropdown menu on either axis provides a list of the variables shown in the Control Bar Region. The two buttons, Enable and Multiple, are used when plotting pairs of variables. If you select pressure for the y-axis and volume for the x-axis, and then select "Enable," these same variables are activated in the Control Bar Region. By scrolling the volume slide bar in the Control Bar Region you will trace out a plot. The Multiple button allows two or more plots to be superimposed.

The Velocities option is a plot of the speed distribution of the sample. The y-axis of this plot represents the number of particles. The x-axis represents the range of velocities starting at zero. The bars in this plot represent the velocities of the particles in the Sample Region. As the velocities of the particles change, the plot is redrawn. The smooth curved line in the plot represents the ideal distribution of the velocities for the gas sample. A vertical line represents the average (root-mean-square average) speed of the sample. This line is the same color as the particles. Observe the behavior of this region while changing each of the variables in the Control Bar Region. If you click on the Enable Tracking button, you can follow the path of a particle in the Sample Region. The length of the tail represents a fixed unit of time, and consequently can be used as a measure of the speed of the particle. This same particle is identified as a red line, labeled with the actual speed (in meters/second), in the speed distribution plot. If you pause the motion of the particles, you can click on different particles to get a measure of their speeds.

If you have any questions check with another student in the class, or your instructor.

Graphic Simulations

Once the browser is running, type the following address into the location-input line of your browser:

http://introchem.chem.okstate.edu/DCICLA/SampleG.htm

This should load a sample Graphic Simulation. Once you have the simulation running, your screen should look similar to what is shown in Figure 3. Although the details of the screen you will see will vary with different MoLE activities, all Graphic Simulations have three important regions. The Strip Chart Region will plot the relative concentrations versus time of all the substances in the reaction to be studied. When you first load the program the Strip Chart Region is blank. It is activated when you click on the Resume button.

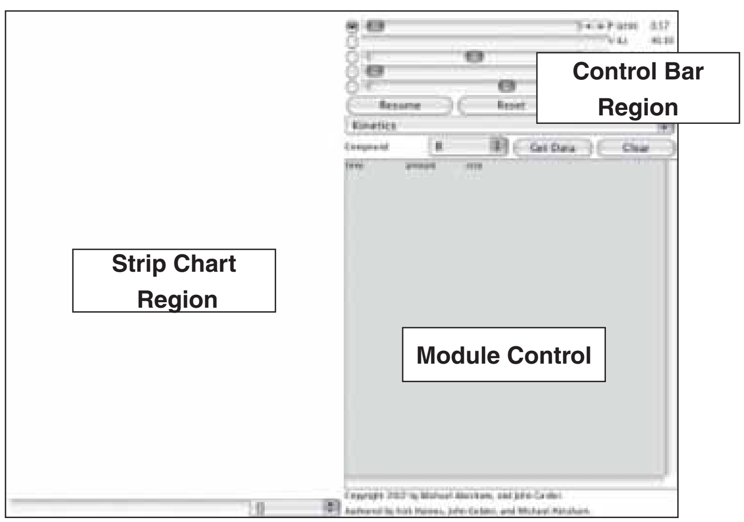


Figure 3.

The Control Bar Region has scrollbars that allow you to change the variables of the experiment. There are scrollbars for pressure (in units of atmospheres), for volume (in units of liters), for the amount of each substance that is active in the Sample Region (in mols), and for temperature (in units of Kelvins). The concentration of each substance can be calculated by dividing the number of mols by the volume of the container. To the left of each scrollbar is a radio button. When selected, that particular variable (called the dependent variable) is calculated based on the value of the other variables. In the default mode the pressure scrollbar's radio button is selected so the pressure of the sample is varied.

As a simple exploration, try moving each of the scrollbars and observe the effect on the strip chart. These effects will be address in more detail in each experiment. You can click the mouse on the Reset button located below the temperature scrollbar to return to the original conditions. The Pause button will suspend the motion in the gas sample.

The region below the Control Bar Region is the Module Display Region. As was the case for the Particulate Simulation, this region allows the data in the other regions to be represented in several ways depending on the particular activity you are doing. These might include energy reaction profiles showing the relative energies of reactants and products of a chemical reaction, and simple graphs comparing variables. To utilize these different functions, use the pull down menu located below the temperature scrollbar.

The Kinetics option allows you to record quantitative information being generated by the strip chart. Three columns of data are generated: time, amount, and instantaneous rate. These data are generated by specifying the compound you want to follow and then clicking on the Get Data button. This can be done as many times during the reaction as you want. These effects will be addressed in more detail in experiments that utilize this function.

The Reaction Viewer shows the reaction profile for a chemical reaction as it proceeds from reactants to products. These effects will be addressed in more detail in experiments that utilize this function.

The Relations option reveals an xy graph with a dropdown menu on each axis. Selecting the dropdown menu on either axis provides a list of the variables shown in the Control Bar Region. The two buttons, Enable and Multiple, are used when plotting pairs of variables. If you select pressure for the y-axis and volume for the x-axis, and then select "Enable," these same variables are activated in the Control Bar Region. By scrolling the volume slide bar in the Control Bar Region you will trace out a plot. The Multiple button allows two or more plots to be superimposed.

If you have any questions, check with another student in the class or your instructor.

MASS AND PARTICLE RELATIONSHIPS

Name ______________________ Section ______________

Log on to the Internet. Type the following address into the location-input line of your browser:

http://introchem.chem.okstate.edu/DCICLA/SRGM1.htm

This will load a Particulate Simulation. Once you have the simulation running, your screen will look like what is shown in Figure 1 below. If you haven't already done so, read the Particulate Simulation section of the Introduction to MoLEs Activities to learn how to use the simulation.

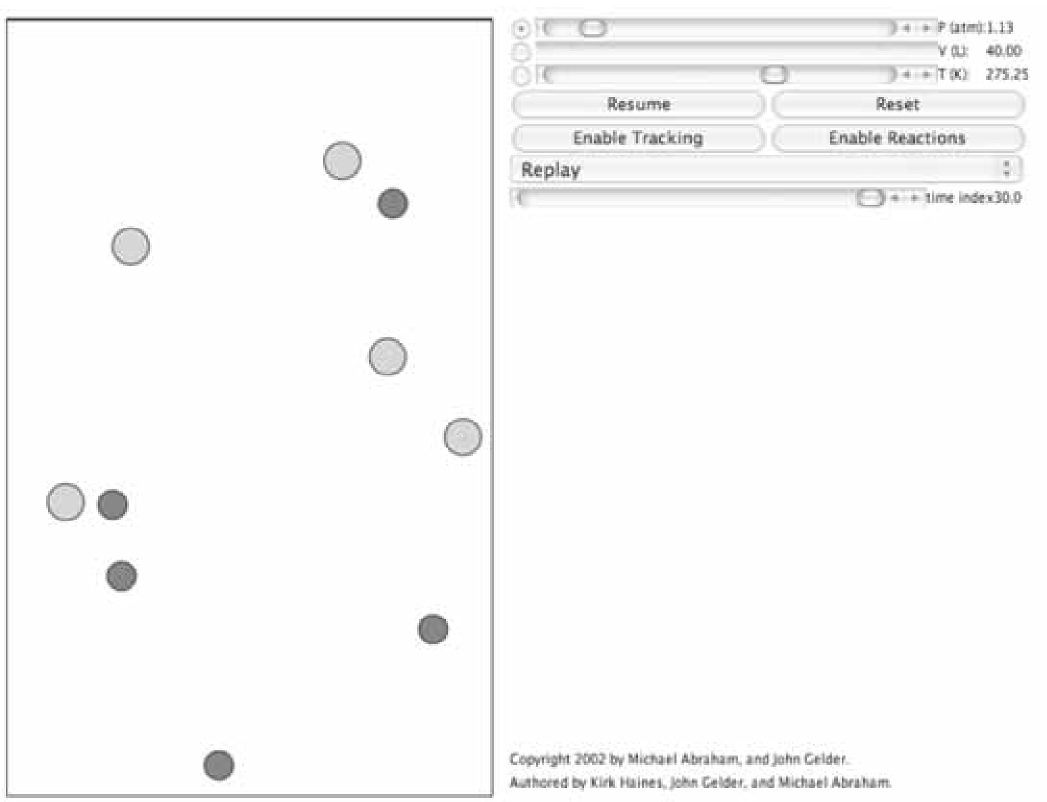


Figure 1.

Problem Statement: How are the numbers of atoms and molecules, and their masses, related in a chemical reaction?

I. Data Collection

A. Click on the Resume button and then the Enable Reactions button and allow the simulation to run. Record your observations of what is happening. Use some or all of the following terms in your description: atom, molecule, particle, collision, speed, energy, reactants, and products. What is (are) the reactant(s) in this reaction? What is (are) the product(s) in this reaction?

B. Reset the simulation but do not enable the reaction. Based on what you observe in the sample region and control bar region of the screen, record the number of particles of R, G, and RG in the table below. A mole is defined as a large number (6.02×10^{23}) of particles. Record the number of moles of R, G, and RG in the table below.

Before the Reaction Occurred

	R	G	RG
# of particles			
# of moles			
Mass/mole			
Mass			

C. If you observe the particles in the sample region, you will notice that the G particles are larger than the R particles. This is because a G particle has twice the mass of an R particle. If one mole of R particles has a mass of 1.00 gram (called the molar mass—in unit of g/mol), what is the molar mass of G and of RG? Record these values in the table above.

D. Click on the Enable Reaction button. Allow the simulation to run until no more changes occur. Click on the Pause button and record your observations in the table below.

After the Reaction Occurred

	R	G	RG
# of particles			
# of moles			
Mass/mole			
Mass			

II. Data Analysis and Interpretation

A. In the boxes below, draw a picture representing the before (reactant) and after (product) state of the chemical reaction you are studying. Be sure to clearly label each particle.

Before (Reactants) After (Products)

B. Write a balanced chemical equation for the reaction you have observed in this simulation. Do this by writing an algebraic-like equation with the reactant particles on the left and the product particles on the right, separated by an arrow (instead of an equals sign) pointing toward the product side of the equation. **Simplify the equation so that no common particles are on both sides of the equation and it represents the lowest ratio of whole numbers of particles.**

C. How did you decide that the reaction had reached completion?

D. The chemical equation is balanced by specifying the number of particles or moles of particles that are found as reactants and products. Do these balancing numbers (coefficients) also represent numbers of grams? Why or why not?

III. Data Collection

A. Type the following address into the location-input line of your browser:

http://introchem.chem.okstate.edu/DCICLA/SRGM2.htm

Before starting the simulation, fill in the table below with the information requested.

Before the Reaction Occurred

	R	G	RG
# of particles			
# of moles			
Mass/mole			
Mass			

B. Click on the Resume and Enable Reactions buttons. Allow the simulation to run until no more changes occur. Click on the Pause button and record your observations. Fill in the table below with the information requested.

After the Reaction Occurred

	R	G	RG
# of particles			
# of moles			
Mass/mole			
Mass			

C. Write a balanced chemical equation for the reaction you have observed in this simulation.

IV. Data Analysis and Interpretation

A. Compare your observations from this experiment with the one you did in section I. How were the reactions similar and how were they different?

B. Compare the equation you wrote for III.C with the one you wrote for section II.B.

C. Predict what would happen if you started the reaction with 5 R particles and 7 G particles.

D. Compare the total amounts of atoms, molecules, and masses for the reactants with the total amounts of atoms, molecules, and masses for the products. Which of these factors are conserved as the reaction proceeds from reactants to products?

	Reactants	Products
Total Mass		
Total Atoms		
Total Molecules		

E. What is the ratio of reacting particles in this reaction? What is the ratio of reacting masses in this reaction? How are these ratios related to each other?

F. If 15 moles of R are combined with 15 moles of G, how many moles of RG will be formed?

G. If 15 g of R are combined with 15 g of G, how many grams of RG will be formed?

V. Data Collection

Open the molecular simulation SG2B2M:

http://introchem.chem.okstate.edu/DCICLA/SG2B2M.htm

A. Click on the Resume button and then the Enable Reactions button and allow the simulation to run. Record your observations of what is happening. Use some or all of the following terms in your description: atom, molecule, particle, collision, speed, energy, reactants, and products. What is (are) the reactant(s) in this reaction? What is (are) the product(s) in this reaction?

B. Using the procedure you used to study the chemical reaction in the previous sections, fill in the table below with the information requested for this new chemical reaction. Each B particle has a molar mass of 1.500 grams per mole (each B_2 particle will have a molar mass of 3.000 grams per mole).

Before the Reaction Occurred

Reactants	G_2	B_2	G_2B
# of particles			
# of moles			
Mass/mole			
Mass			

After the Reaction Occurred

Products	G_2	B_2	G_2B
# of particles			
# of moles			
Mass/mole			
Mass			

C. Write a balanced chemical equation for the reaction you have observed in this simulation.

VI. Interpretation and Conclusions

A. Write a rule for determining the molar mass of a molecule.

B. What quantities are conserved in a chemical reaction?

C. A limiting reagent is defined as a reactant in a chemical reaction that limits or controls the amount of product that is formed. What was the limiting reagent in each of the reactions you studied in this activity?

Reaction (Section #)	Limiting Reagent
II.B	
IV.B	
V.C	

D. If 20.0 moles of G_2 are reacted with 10.0 moles of B_2, how many moles of G_2B will be formed?

E. If 20.0 g of G_2 are reacted with 10.0 g of B_2, how many grams of G_2B will be formed?

VII. Data Collection

Type the following address into the location-input line of your browser:

http://introchem.chem.okstate.edu/DCICLA/SRGN.htm

This will load a Graphic Simulation. Once you have the simulation running, your screen will look like what is shown in Figure 2 below. If you haven't already done so, read the Graphic Simulation section of the Introduction to MoLEs Activities to learn how to use the simulation.

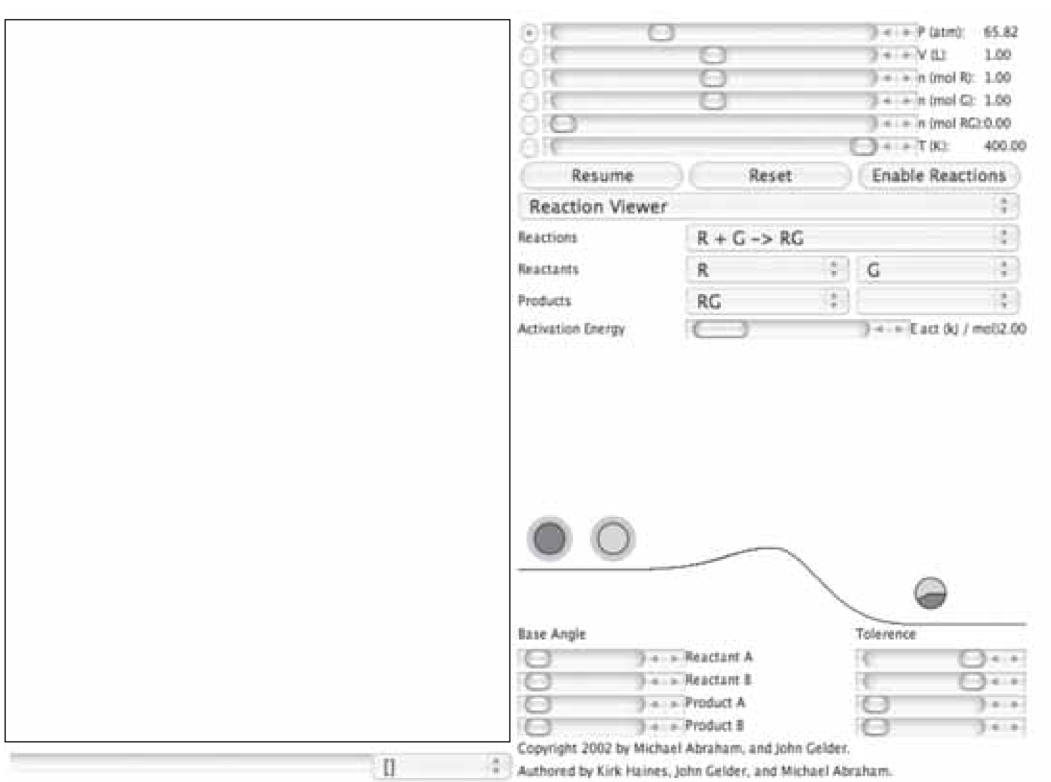


Figure 2.

A. Using the data from the Control Bar Region, enter the initial amounts (moles) of each substance in the equation into the table (called an ICE table) below.

	R +	G →	RG
Initial Amount (moles) – I			
Change (moles) – C			
Ending Amount (moles) – E			

B. Click on the Resume and then the Enable Reactions buttons to begin the reaction. When the reaction appears to be complete, click Pause to stop the action. Record the values of the ending concentrations in the table in Section A. Calculate and record the change in numbers of moles of each of the substances in the reaction. In the space below, draw the appearance of the strip chart and label the axes. If necessary, use the scrollbar located under the strip chart to move the chart back to the beginning of the reaction. Identify the chemical substance that corresponds to each of the colored lines.

C. The molar masses for the atoms in this activity are: R = 1.00 g, G = 2.00 g, and B = 1.50 g. Use this information to convert the molar data from the previous sections to fill in the ICE table below with masses of the reactants and products in grams.

	R +	G →	RG
Initial Amount (grams) – I			
Change (grams) – C			
Ending Amount (grams) – E			

VIII. Interpretation and Conclusions

A. Explain what is happening to each of the reactant and product substances over time. How does the strip chart illustrate the changes you observe?

B. How can you tell when the reaction is complete? What substances are present when the reaction appears to be complete?

C. Identify the limiting reagent for the reaction. What reagent is in excess and how much excess is there?

D. Consider the reaction you studied in section V between G_2 and B_2. If 5.0 g of G_2 are combined with 5.0 g of B_2, how many grams of G_2B is formed? Set up an ICE table like the ones used in previous sections. Identify any limiting reagents present and the number of grams of any reactants that are left in excess. Open the molecular simulation SG2B2N: http://introchem.chem.okstate.edu/DCICLA/SG2B2N.htm to confirm your conclusions.

MASS AND PARTICLE SYSTEMS

System

Investigate the mass and particle relationships of chemical reactions:

The molar masses for atoms are: R = 1.00 g, G = 2.00 g, and B = 1.5 g

A. Molecular: http://introchem.chem.okstate.edu/DCICLA/S2GBM.htm

B. Molecular: http://introchem.chem.okstate.edu/DCICLA/SRGBM.htm

C. Graphic: http://introchem.chem.okstate.edu/DCICLA/SRBN.htm

RESEARCH STATEMENTS

Use evidence from the MoLE simulations to prove or disprove the following statements.

1. Molecules are conserved in a chemical reaction.
2. Mass is conserved in a chemical reaction.
3. Moles are conserved in a chemical reaction.
4. The coefficients in a balanced chemical equation are related to the initial number of moles of reactants and products.
5. The coefficients in a balanced chemical equation are related to the initial number of grams of reactants and products.
6. Increasing the amount of a reactant will proportionally increase the amounts of a product.
7. The initial ratio of masses in a chemical reaction and the initial ratio of moles in a chemical reaction are the same.

Name _______________________________ Section _______________

Log on to the Internet. Type the following address into the location-input line of your browser:

http://introchem.chem.okstate.edu/DCICLA/GLHeNeAr.htm

This will load a Particulate Simulation. Once you have the simulation running your screen, will look like what is shown in Figure 1 below. If you haven't already done so, read the Particulate Simulation section of the Introduction to MoLEs Activities to learn how to use the simulation.

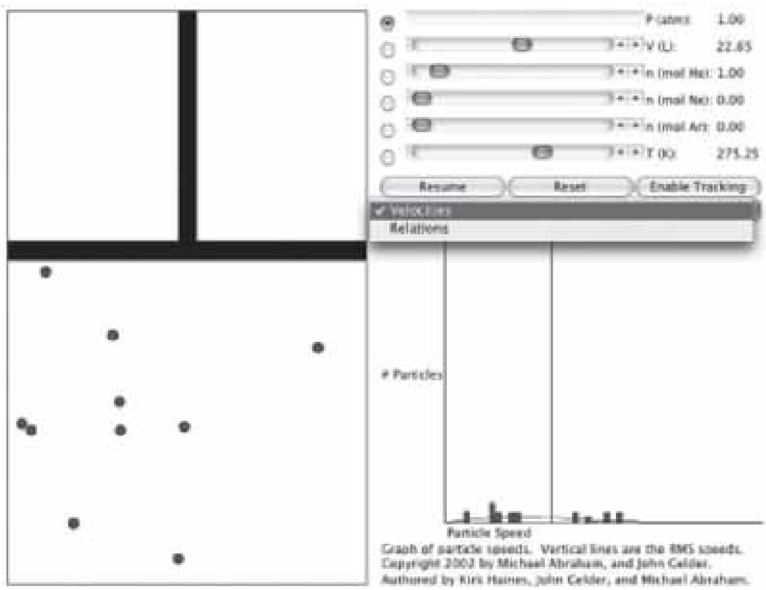


Figure 1.

Problem Statement: How are the pressure and volume of a gas sample related?

I. Data Collection

A. Open the Gas Law Simulation program and observe and describe, in the space below, the activity in the Gas Sample window. Consider using some or all of the following terms in your description: particles, atoms, molecules, collisions, speed, energy, force.

B. Enable the tracking function and trace the path of a particle from one side of the screen to the other in the space below. Explain any changes in speed or direction that you observe.

C. Record the values for pressure, volume and temperature on the digital read-outs of the Control Bar window.

D. Observe the action in the Velocities window. Relate what you see with the behavior of the objects in the Gas Sample window.

Click the Pause button and sketch and label the graph in the space below.

E. Using the controls in the Control Bar window, fix Pressure as a dependent variable by clicking on its radio button. Change the volume of the container using the Volume slider bar and observe what happens to the pressure of the system. Also observe what happens in the Speed Distribution window. Explain how the activity in the Gas Sample window accounts for your observations.

F. Collect five additional observations of volume/pressure relationships and record all of your data in the following table.

Data Table

Pressure (atm)	Volume (L)

II. Data Analysis

What patterns are shown in these data? It might be helpful to graph the data. Try to come up with an algebraic equation that expresses the pattern you found.

III. Interpretation and Conclusions

A. How are the pressure and volume of a gas sample related?

B. Mental Model: Draw a picture(s) that explains how the pressure and volume of a gas sample are related at the level of atoms and molecules, and that illustrate(s) the observations you made in the experiment. In words, explain how your picture(s) illustrate(s) this relationship.

C. Using your data, predict the pressure of a gas sample at a volume of 100 L. Show how you made your prediction.

GAS PRESSURE AND TEMPERATURE RELATIONSHIPS

Name ______________________ Section ______________

Log on to the Internet. Type the following address into the location-input line of your browser:

http://introchem.chem.okstate.edu/DCICLA/GLHeNeAr.htm

This will load a Particulate Simulation. Once you have the simulation running, your screen will look like what is shown in Figure 1 below. If you haven't already done so, read the Particulate Simulation section of the Introduction to MoLEs Activities to learn how to use the simulation.

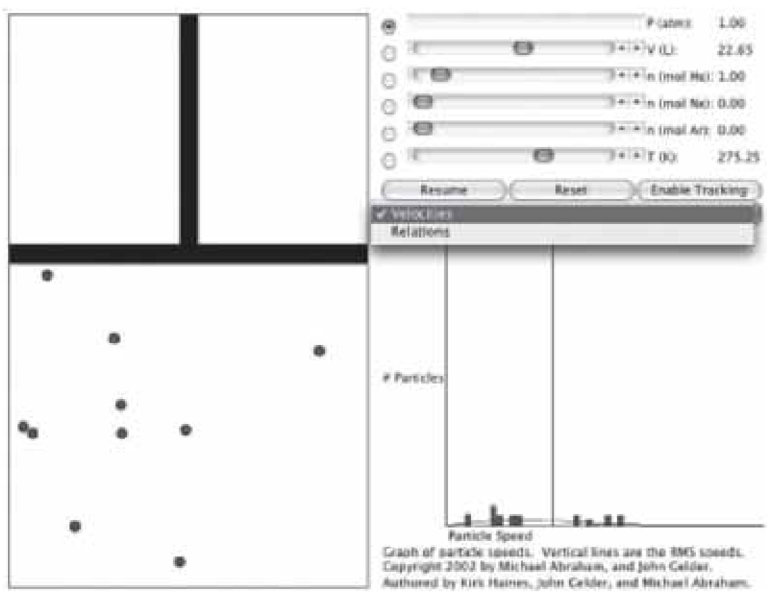


Figure 1.

Problem Statement: How are the pressure and temperature of a gas sample related?

I. Data Collection

A. Open the Gas Law Simulation program and observe and describe, in the space below, the activity in the Gas Sample window. Consider using some or all of the following terms in your description: particles, atoms, molecules, collisions, speed, energy, force.

B. One of the objects in the window is colored differently than the others. Enable the tracking function and trace the path of a particle from one side of the screen to the other in the space below. Explain any changes in speed or direction that you observe.

C. Record the values for pressure, volume and temperature on the digital readouts of the Control Bar window.

D. Observe the action in the Speed Distribution window. Relate what you see with the behavior of the objects in the Gas Sample window.

Click the Pause button and sketch and label the graph in the space below.

E. Using the controls in the Control Bar window, change the temperature in the container and observe what happens to the pressure of the system. Also observe what happens in the Speed Distribution window. Explain how the activity in the Gas Sample window accounts for your observations.

F. Collect five additional observations of pressure/temperature relationships and record all of your data in the following table.

Data Table

Pressure	Temperature

II. Data Analysis

What patterns are shown in these data? It might be helpful to graph the data. Try to come up with an algebraic equation that expresses the pattern you found.

III. Interpretation and Conclusions

A. How are the pressure and temperature of a gas sample related?

B. Mental Model: Draw a picture(s) that explains how the pressure and temperature of a gas sample are related at the level of atoms and molecules, and that illustrate(s) the observations you made in the experiment. In words, explain how your picture(s) illustrate(s) this relationship.

C. Using your data, predict the pressure of a gas sample at a temperature of 10 Kelvins. Show how you made your prediction.

GAS SYSTEMS

System 1
Investigate the relationship between the volume and temperature of a gas sample at constant pressure and amount.

System 2
Investigate how the number of gas particles affects the pressure of a gas sample.

System 3
Compare and interpret pressure vs. volume relationships of gas samples at different temperatures.

System 4
Investigate the average speed (distance per unit time) of particles in a gas as a function of pressure, volume, amount, or temperature.

System 5
Investigate the average number of collisions between particles or with the container walls in a gas sample as a function of pressure, volume, amount, or temperature.

System 6
Investigate any of the above systems using different kinds of particles or combinations of particles.

System 7
Investigate any other gas system or investigate a modification of any of the above systems.

RESEARCH STATEMENTS

Use evidence from the MoLE simulation to prove or disprove the following statements.

1. The total pressure of a combination of gases is equal to the sum of the individual pressures exerted by each gas.
2. If you increase the pressure on a gas sample by decreasing the volume, the gas particles will speed up.
3. The pressure exerted by a gas depends on its molar mass.
4. The speed of a gas particle depends on its molar mass.
5. The kinetic energy of a gas particle depends on its molar mass.
6. Gas particles slow down when they collide with the walls of a container.

7. The speeds of gas particles are not affected by collisions with other gas particles.
8. The average speed of two like gas particles before a collision is equal to the average speed after the collision.
9. The average speed of two unlike gas particles before a collision is equal to the average speed after the collision.

Molecular Modeling

Introduction to Molecular Modeling

In the following laboratory activities you will examine three-dimensional models of molecules using the computer-based molecular viewing program called Jmol.[*] You can access a version of Jmol for use with these activities at http://introchem.chem.okstate.edu/DCICLA/jmol/jmol.php.

Instructions

After obtaining access to the Jmol program you should see an image on your computer screen that looks similar to the following figure.

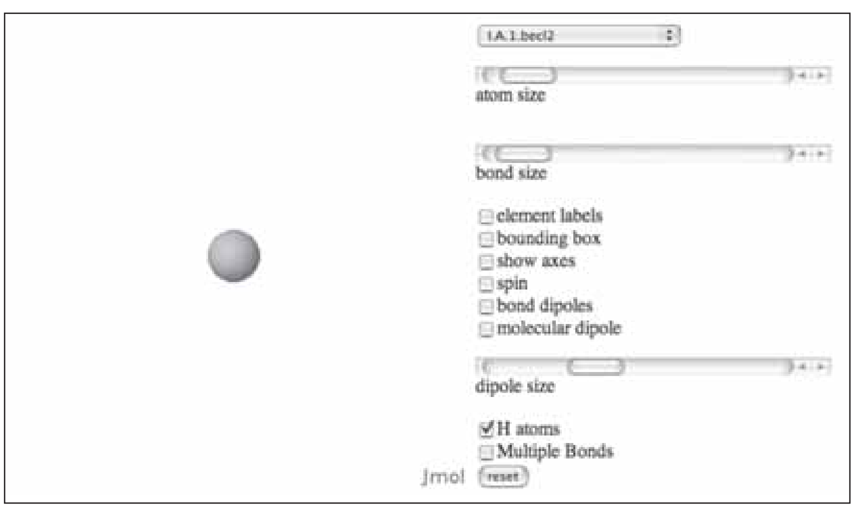


Figure 1.

* Jmol is a free, open source molecule viewer for students, educators, and researchers in chemistry and biochemistry. It is cross-platform, running on Windows, Mac OS X, and Linux/Unix systems (see: http://jmol.sourceforge.net/). A team of researchers are updating and improving the program on a constant basis. Robert Hanson of St. Olaf College has been particularly helpful to the authors of these activities.

You can view the molecules you will need for the following activities through the dropdown menu on the upper right of your screen. The names of the molecules are labeled so that they correspond to the activities. So, for example, the molecules for the I. VSPER activities are labeled with a “I.” All of the molecules are labeled by number and alphabet in outline form and listed in order to make them easy to find.

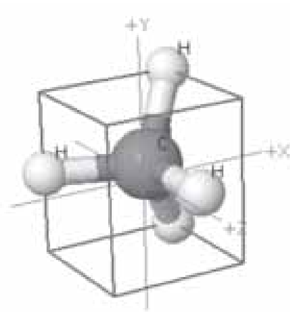
As an example, let’s open the file for methane, CH_4. It can be found in the Jmol menu list as I.C.1.ch4. Highlight the molecule in the list and then click. The molecule window should now be showing the CH_4 molecule:

Jmol

Figure 2.

You can now interact with the molecule in a number of different ways. To rotate the molecule, click anywhere in the window and drag your mouse around. You can rotate the molecule in the plane of the screen and resize it by using the shift key when you click/drag the mouse side by side or up and down.

There are a number of different ways of viewing the molecule. The Jmol window has a number of operations that can be utilized by a click box or slider bar. These include: slider bars to control atom and bond size, click boxes to label the atoms, superimpose bounding boxes, add axes, spin the molecule, add bond and molecule dipoles, display molecules with and without H atoms, and display multiple bonds in molecules that have them. Try each function out to see how it affects the molecule. In addition, you can access a number of other functions by control clicking (Mac) or right clicking (PC) in the molecule window.

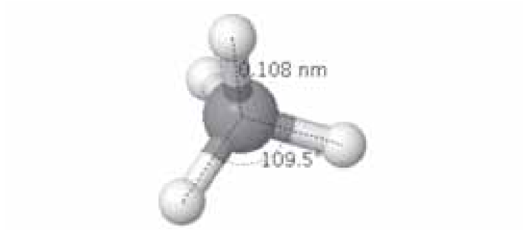


Jmol

Figure 3.

To measure a bond length, hold the cursor over an atom until an atom label appears. Double click on the atoms. A plus sign should replace the cursor arrow. As you move the plus sign to another atom a colored dotted line should appear. When you place the cursor over a second atom, double click on it when the atom label appears. The colored line should change color and a value for the length should appear. Jmol seems to be a little sensitive to this operation so you might have to try this several times.

To measure a bond angle, double click on one of the end atoms when the atom label appears. Then drag the plus cursor to the middle atom in the angle. Single click on this atom when the atom label appears, then move the cursor to the other end atom and double click when the atom label appears. The angle in degrees should appear as the dotted line changes color.



Jmol

Figure 4.

If you want to compare two or more molecules, you can open additional browser windows.

I. VSEPR*

Name ______________________ Section ______________

For this activity, all of the file labels will begin with a Roman numeral I. Each of the questions asks you to examine molecules that are designated with letters. For example, for part A, all of the molecule files will be labeled I.A.

It may be helpful for you to refer to the table of molecular geometries found in most general chemistry textbooks.

A. Using Jmol, examine the two molecules labeled I.A. Write the molecular formula for each molecule. Draw and label the molecules and measure and record their bond angles.

B. Using Jmol, examine the two molecules labeled I.B. Write the molecular formula for each molecule. Draw and label these molecules and measure and record their bond angles. Draw the Lewis structure for each molecule. Why is SO_2 shaped like it is and is not linear? How is it different from the molecules in section A? What is similar about all of the molecules in List B? Describe any difference between the angles you measure and the theoretical ones (see your textbook to see what the theoretically expected angles should be).

* VSEPR—Valence Shell Electron Pair Repulsion Theory

C. Repeat step B for the three molecules labeled I.C (i.e., open them, measure their bond angles, and draw the Lewis structures). Write the molecular formula for each molecule. What is similar about all of the molecules in List C? Compare the actual bond angles with the theoretically expected angles. Explain any trend in bond angles that you observe.

D. All of the five molecules Labeled I.D have five regions of electron density around the central atom. Open the I.D.1.pf5 molecule, and examine the two different FPF angles in the molecule. Draw and label this molecule. Predict where the lone pairs will go in molecules that have one, two, and three lone pairs. Now, open the other files, write the molecular formula for each molecule, measure their bond angles, and draw the molecules. Were your predictions correct? At what locations do the lone pairs go in five-coordinate molecules?

E. Using Jmol, examine the three molecules labeled I.E, all of which have six regions of electron density. Write the molecular formula for each molecule. Draw the molecules and measure their bond angles. Draw the Lewis structure for each molecule. How do nonbonding (lone pair—LP) electrons explain the molecular geometries of XeF_4 and IF_5? Explain any differences you notice between the theoretically expected bond angles and your observed values.

II. CARBON COMPOUNDS

Name

Section

For this activity, all of the file labels will begin with a Roman numeral II.

A. Bond Types

1. In Jmol, open the II.A.1, II.A.2, and II.A.3 molecules. Activate the multiple bond function. Measure and record the carbon-to-carbon bond lengths for single (CH3CH3), double (CH2CH2), and triple (CHCH) bonds. Make a generalization comparing the lengths of single, double, and triple bonds. Propose a reason for your generalization.

2. Draw the Lewis structure for benzene (C_6H_6) and predict the carbon-to-carbon bond lengths in the molecule. Using Jmol, open II.A.4, the benzene molecule (C6H6), and measure the carbon-to-carbon bond lengths. Is your prediction correct? Compare the bond lengths in benzene to those of the single, double and triple bond in section A.1. Does benzene contain single and/or double C–C bonds? Why? How do you explain your observations?

B. Cyclic Compounds

In Jmol, open the three six carbon cyclic structures in II.B.1, II.B.2, and II.B.3. Compare and contrast these molecules. Focus on the C–C bond types and the geometries of these compounds.

C. Summary

From A and B, what relationship did you find between (carbon-to-carbon) bond types and molecular geometries?

III. PERIODIC TRENDS

Name ______________________ Section ______________

For this activity, all of the file labels will begin with a Roman numeral III.

A. Draw the Lewis structures for the molecules ONBr, ONCl, ONF, and ONI. Predict the molecular geometries and bond angles for each molecule.

B. In Jmol, examine the four molecules labeled III.A. Draw and label the molecules and measure and record their bond lengths and bond angles.

C. Identify any trends you observe in the measurements you recorded. How are these trends related to the periodic table and to electron configurations? Explain why these trends exist.

D. Draw the Lewis structures for the molecules CH_3F, CH_3CH_3, CH_3OH, and CH_3NH_2. Predict the molecular geometries and bond angles for each molecule.

E. In Jmol, examine the four molecules labeled III.B. Draw and label the molecules and measure and record their bond lengths and bond angles.

F. Identify any trends you observe in the measurements you recorded. How are these trends related to the periodic table and to electron configurations? Explain why these trends exist.

IV. SOLIDS

Name ______________________ Section ______________

For this activity, all of the file labels will begin with a Roman numeral IV.

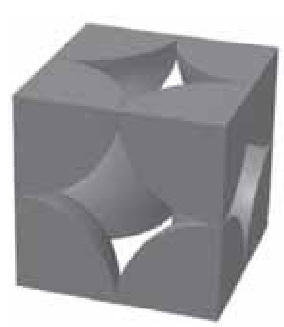
A. In Jmol, open the SCS file in IV.A.1. Click the Bounding Box and Axes function keys. Use the atom size and bond size slider bars to adjust the view so that the bounding box and axes can be easily seen. Move the figure around to a position that shows the 3-D orientation of the spheres and draw the figure below.

B. This figure is the basis for some solid compounds and ions. This particular structure is called a Simple Cubic packing Structure (SCS) and is one way atoms, ions, or molecules are arranged in a three-dimensional matrix (called a lattice). Polonium, Iridium, and Ruthenium are examples of the few elemental solids that utilize the SCS arrangement. The Jmol figure is the simplest unit of the SCS structure. A sample of a solid substance would be represented by adding spheres in the x, y, and z planes to make a large matrix. Describe the orientation of the spheres to each other in this matrix.

Taking the continuous nature of the lattice into account, how many nearest neighbors does each sphere have? __________ This number is called the coordination number.

The Bounding box defines what is called the Unit Cell for the structure. The lattice can be constructed by repeating unit cells in the x, y, and z directions. Only the spheres or partial spheres that are inside of the bounding box are considered to be in the unit cell (see figure).

How many spheres are contained in the SCS unit cell? ________



C. Adjust the sizes of the spheres using the atom size slider bar until the spheres just touch each other. The space between the spheres (called a Hole) can be occupied by other atoms, ions or molecules depending on their sizes. As an example, if the spheres showing in the Jmol figure are the anions of an ionic salt, the hole could contain the cation.

If all of the holes in an SCS lattice were filled, what would be the ratio of cations to anions?________

Estimate the relative maximum sizes of the cations and anions in an SCS lattice.

D. Calculate the density (packing efficiency) of the SCS packing arrangement. (Hint: Calculate the volume of the spheres [the sum of all the parts] contained in the unit cell and divide that by the total volume of the unit cell. The dimensions can be determined from the bond lengths.)

E. Another solid packing structure is the body centered cubic packing or BCC. In Jmol, open the BCC file (IV.A.2). Use the atom size and bond size slider bars to adjust the view so that only the spheres are showing. The alkali metals are examples of the elemental solids that utilize the BCC arrangement. Draw this unit cell structure and describe the orientation of the spheres to each other. Why is this structure called body centered cubic?

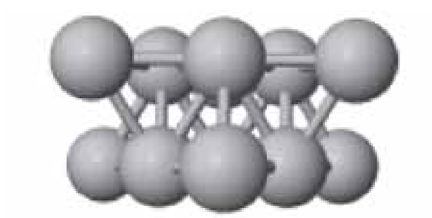
F. Use the same procedure that you used for the SCS structure to answer the following questions.

What is the coordination number for BCC packing? __________

How many spheres are contained in the BCC unit cell? ________

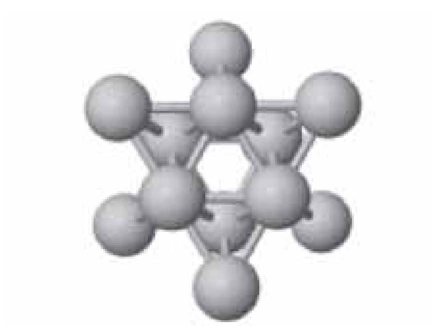
Calculate the density (packing efficiency) of the BCC packing arrangement. (When you adjust the size of the spheres, make them as large as possible without overlapping the boundaries of any of the spheres.)

G. In Jmol, open the CP file (IV.A.3). Adjust the atom and bond sizes. This kind of packing is called a closest packing structure. It is called a closest packing arrangement because the spheres are packed together as close as they can be. Manipulate the model until you can see two layers of spheres viewed from the side.



How is this packing arrangement different from the SCS and BCC packing?

Rotate the structure to view it from the top.



If you were to place a third layer on top of this structure you have two choices. Describe how these two structures would be different from each other. (Hint: One would have what is called an *abab* orientation and the other would have an *abcabc* orientation. What do you think this means?)

H. One of these two possible closest packing arrangements is called face centered cubic packing (FCC). In Jmol, open the FCC file (IV.A.4). Adjust the atom and bond sizes. Al, Ni, Cu, and Ag are examples of elemental solids that utilize the FCC arrangement. This arrangement is also called Cubic Closest Packing or CCP. It is called a closest packing arrangement because the spheres are packed together as close as they can be. Draw this unit cell structure and describe the orientation of the spheres to each other. Manipulate the model so as to convince yourself that this cube comes out of a closest packing structure. Draw this structure. Which of the two orientations, *abab* or *abcabc*, is this?

I. Use the same procedure that you used for the SCS and BCC structures to answer the following questions.

What is the coordination number for FCC packing? __________

How many spheres are contained in the FCC unit cell? ________

Calculate the density (packing efficiency) of the FCC packing arrangement.

J. The second of the two possible closest packing arrangements is called hexagonal closest packing (HCP). In Jmol, open the HCP file (IV.A.5). Adjust the atom and bond sizes. Unlike FCC, SCS, and BCC, this arrangement does not form a cube. Co, Zn, and Cd are examples of elemental solids that utilize the HCP arrangement. Draw this unit cell structure and describe the orientation of the spheres to each other. Manipulate the model so as to convince yourself that it comes out of a closest packing structure. Which of the two orientations, *abab* or *abcabc*, is this?

K. Use the same procedure that you used for the SCS and BCC structures to answer the following questions.

What is the coordination number for HCP packing? __________

In Jmol, open the HCPuc file (IV.A.6). Use the HCPuc file to help define the unit cell. How many spheres are contained in the HCP unit cell? ________

Optional: Calculate the density (packing efficiency) of the HCP packing arrangement.

L. Although it's not obvious why different elemental metals are found in different packing arrangements, there are some that can be rationalized. How does the packing arrangement for the alkali metals, which are soft enough to be cut with a knife, explain differences with metals such as copper and silver, which are harder and cannot be cut with a knife?

M. In Jmol, open the NaCl.LM file (IV.B.1). In a separate window, open the NaCl file (IV.B.2). This lattice represents NaCl. What packing arrangement is used by the Na^+ ions? Describe the orientation of the holes that contain the Cl^- ions.

N. In Jmol, open the CsCl.LM file (IV.B.3.CsCl). In a separate window, open the CsCl file (IV.B.4.CsCl). This lattice represents CsCl. What packing arrangement is used by the Cs^+ ions? What packing arrangement is used by the Cl^- ions?

Since both Na and Cs are alkali metals, what can account for the differences in their packing structures?

O. In Jmol, open the Diamond file (IV.B.5). In a separate window, open the Graphite file (IV.B.6). Compare the atomic make up of these two compounds. How are they similar? Compare the structures of the two compounds. Graphite is used as a dry lubricant. Diamond is used on saw blades. How do the solid crystal structures account for the different physical properties of graphite and diamond?

V. ISOMERISM

NAME ______________________ SECTION ______________

For this activity, all of the file labels will begin with a Roman numeral V.

A. In Jmol, open the $C_2H_4Cl_2$ 1 file (V.A.1). Open a new window and then open the $C_2H_4Cl_2$ 2 file (V.A.2). Using the slider bar and clicker box function keys, make any adjustments to the molecules you want to aid viewing. Manipulate the molecules so that you can compare them. Draw a Lewis structure for each molecule. Discuss the structural differences between the molecules.

B. Although both molecules have the same formula, $C_2H_4Cl_2$, they have different physical and chemical properties. For example, the molecule labeled 1 has a boiling point of 57.3 °C, and the molecule labeled 2 has a boiling point of 83.5 °C. Molecules that have the same chemical formulas but different structures are called isomers. The rule for identifying differences is to superimpose the molecules on each other. If all of the atoms match, the molecules are identical. If not, the molecules are isomers. Sometimes, however, superimposing can be tricky. Molecules can be manipulated by rotating the atoms around their bonds. Unless fixed into position, atoms connected by single bonds can be rotated. Atoms connected by multiple bonds, however, cannot be rotated. Open the $C_2H_4Cl_2$ 3 file (V.A.3) in a separate window and draw its Lewis structure. Compare the molecule with the $C_2H_4Cl_2$ 1 and $C_2H_4Cl_2$ 2 files. What is its relationship to each of these two molecules?

C. In Jmol, open the three $C_2H_2Cl_2$ molecules (V.B.1, V.B.2, and V.B.3) in new windows. Activate the multiple bond function. In the Preferences menu, make any adjustments to the molecules you want to aid viewing. Manipulate the molecules so that you can compare them. Draw a Lewis structure for each molecule. Discuss the structural differences between the molecules. How are each of the molecules related to each other?

D. There are several types of isomers. Structural isomers have the same number and kinds of atoms in the molecules, but the atoms are bonded to different atoms. Geometric isomers have the atoms bonded to the same atoms, but they are arranged differently. If similar chemical units are found on the same side of the molecule when a plane divides the molecule in half, these chemical units are said to be "cis" to each other. If they are on opposite sides they are said to be "trans" to each other. In Jmol, open the six isomers of C_4H_8 (V.C.1–V.C.6). View each molecule and draw the Lewis structures of these isomers. For a less cluttered view of the molecules, use the H atoms function to remove the H atoms. Discuss the isomeric relationship of each of these molecules to each of the others.

E. Optical isomers are another isomer type. An optical isomer is characterized as a molecule that is a mirror image of another molecule. Of course, in order to be an isomer it also cannot be superimposed on that molecule. Optical isomers can be important biochemical molecules. For example, a molecule might be an effective drug while its optical isomer is not. The most common type of optical isomer has a carbon atom with four different chemical units attached to it. This carbon is called a chiral center. In Jmol, open the three CHFClBr molecules (V.D.1, V.D.2, and V.D.3). Use the atom size and bond size slider bars to make any adjustments to the molecules you want to aid viewing. Manipulate the molecules so that you can compare them. Draw a structural formula for each molecule. Discuss the isomer relationships between the molecules.

F. Explain why CH_2ClBr and CH_2Cl_2 do not have optical, geometric, or structural isomers.

G. In Jmol, open the $Co(en)_2Cl(NH_3)$ molecules (V.E.1, V.E.2, and V.E.3). Use the atom size and bond size slider bars to make any adjustments to the molecules you want to aid viewing. For a less cluttered view of the molecules, remove the H atoms. Manipulate the molecules so that you can compare them. Draw a structural formula for each molecule. Discuss the isomer relationships between the molecules.

H. In Jmol, open the two the $Co(en)_3$ molecules (V.F.1 and V.F.2). Use the atom size and bond size slider bars to make any adjustments to the molecules you want to aid viewing. For a less cluttered view of the molecules, remove the H atoms. Manipulate the molecules so that you can compare them. Draw a structural formula for each molecule. Discuss the isomer relationships between the molecules.

I. In Jmol, open the two dimethylcyclobutane molecules (V.G.1 and V.G.2). Use the atom size and bond size slider bars to make any adjustments to the molecules you want to aid viewing. For a less cluttered view of the molecules, remove the H atoms. Manipulate the molecules so that you can compare them. Draw a structural formula for each molecule. Discuss the isomer relationships between the molecules.

J. In Jmol, open the three MX_2Y_3 molecules (V.H.1, V.H.2, and V.H.3). Use the atom size and bond size slider bars to make any adjustments to the molecules you want to aid viewing. Draw a structural formula for each molecule. Manipulate the molecules so that you can compare them. Discuss the isomer relationships between the molecules.

K. In Jmol, open the two MX_2Y_4 molecules (V.I.1 and V.I.2). Use the atom size and bond size slider bars to make any adjustments to the molecules you want to aid viewing. Manipulate the molecules so that you can compare them. Draw a structural formula for each molecule. Discuss the isomer relationships between the molecules.

L. In Jmol, open the two MX_3Y_3 folders (V.J.1 and V.J.2). Use the atom size and bond size slider bars to make any adjustments to the molecules you want to aid viewing. Manipulate the molecules so that you can compare them. Draw a structural formula for each molecule. Discuss the isomer relationships between the molecules.

VI. POLARITY

Name

Section

For this activity, all of the file labels will begin with a Roman numeral VI.

A. Some atoms have a greater attraction for electrons than others. A rough measure of this attraction can be assigned to atoms. The electronegativity is such a measure that can be found in most textbooks. It is defined as the relative ability of an atom that is bonded to another atom to attract electrons to itself. You might want to have an electronegativity table to use for this activity. The consequence of two atoms in a bond having a different attraction for electrons is that more negative charge will accrue to one side of the bond, resulting in an electrical polarity. The bond is said to be a dipole with a negative and a positive side. In Jmol, open the HF molecule (VI.A.1). Activate the bond dipole checkbox. The dipole may be easier to view if you reduce the atom and bond sizes and adjust the dipole size. Draw the Lewis structure of the molecule, label the molecule and sketch in the bond dipole. Indicate the negative and positive end of the dipole.

B. Draw the Lewis structure for O_2. Do you expect the O_2 bond to be polar, or nonpolar? Why? In Jmol, open the O_2 molecule (VI.A.2) to check your prediction.

C. Draw the Lewis structure for CS. Do you expect the CS bond to be polar, or nonpolar? Why? In Jmol, open the CS molecule (VI.A.3). Label the Lewis structure of the molecule and sketch in the bond dipole. Indicate the negative and positive ends of the dipole.

D. Molecules that have more than two atoms will have more than one bond. Each of these bonds can be assigned a dipole. Draw the Lewis structure for CS_2. Do you expect each CS bond to be polar, or nonpolar? Why? In Jmol, open the CS_2 molecule (VI.A.4). Label the Lewis structure of the molecule and sketch in the bond dipoles. Indicate the negative and positive ends of the dipoles. Compare the relative strength of the two dipoles. Predict how these bond dipoles combine and how they would affect the overall polarity of the molecule. This resultant polarity is called the dipole moment of the molecule.

E. In Jmol, open the CS_2 and OCS molecules (VI.A.4 and VI.A.5). Label the Lewis structures of the molecules and sketch in the bond dipoles. Indicate the negative and positive ends of the dipoles. Activate the atom dipole checkbox in Jmol for each molecule. Compare the relative strength of the two dipoles in OCS. Predict how these bond dipoles combine and how they affect the overall polarity of the molecules. Activate the molecule dipole checkbox in Jmol for each molecule. Discuss the reasons for any differences between these two molecules.

F. Draw Lewis structures for H_2O, NH_3, CH_4 and CH_3Cl. Draw the 3-D geometries of the molecules and indicate the bond dipoles in your drawings. In Jmol, open these molecules (VI.B.1–VI.B.4) and confirm your drawings. Activate the atom dipole checkbox in Jmol for each molecule. Compare the relative strength of the dipoles. Predict how these bond dipoles combine and how they affect the overall polarity of the molecule. Activate the molecule dipole checkbox in Jmol. Discuss the reasons for any differences between these molecules.

G. Propose a set of rules that will determine if a molecule will be polar or nonpolar.

H. Draw Lewis structures for BF_3, NH_3 and ClF_3. Draw the 3-D geometries of the molecules and indicate the bond dipoles in your drawings. In Jmol, open these molecules (VI.C.1–VI.C.3) and confirm your drawings. Activate the atom dipole checkbox in Jmol for each molecule. Compare the relative strength of the dipoles. Predict how these bond dipoles combine and how they affect the overall polarity of the molecule. Activate the molecule dipole checkbox in Jmol. Discuss the reasons for any differences between these molecules.

I. Compare BF_3 (VI.C.1) with BF_2Cl (VI.C.4). Draw the 3-D geometries of the molecules and indicate the bond and molecular dipoles in your drawings. Discuss the reasons for any differences between these molecules.

Laboratory Simulations

Introduction to Laboratory Simulations

In the following activities you will examine chemical concepts in a simulated laboratory setting. To do these activities you will need to make sure your browser has the latest plug-in to Macromedia Flash™ and Shockwave™. Go to the macromedia website at http://www.adobe.com/downloads/ to obtain them.*

* Most of the software used in these laboratory simulations was developed and programmed by Thomas Greenbowe, Han-Chin Liu and Rohini Vanchiswaran. © Thomas Greenbowe, September 2001 – Project supported by NSF-CCLI-EMD #0088709. The Electron Configuration software was developed by Nancy Gettys and John I. Gelder.

HEATING A HYDRATE

Name

Section

Problem Statement: What happens to the mass of a hydrate when it is heated?

I. Data Collection

A. Go to http://introchem.chem.okstate.edu/DCICLA/Empirical.html and open the Heating a Hydrate Simulation. Your screen should look like the figure below. Showing is a container of the compound hydrated copper(II) sulfate, $CuSO_4(H_2O)_x$—also written $CuSO_4 \cdot xH_2O$.

Figure 1.

Click on the arrow button to advance to the second screen. Your screen should now look like the figure below.

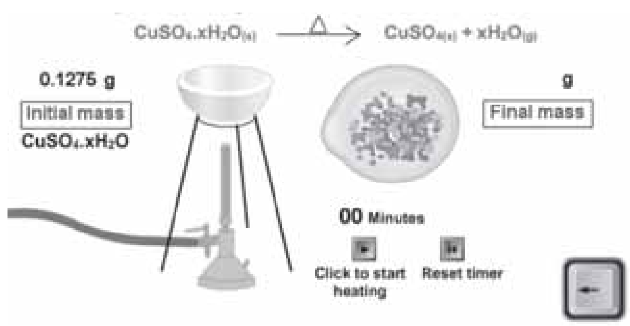


Figure 2.

The apparatus represents a crucible that contains a measured amount of hydrated copper(II) sulfate. The equation for the reaction is displayed. By clicking on the start button you can heat the hydrated copper(II) sulfate and observe what happens.

B. Go to the second screen and click on the Start button. Record your observations below.

C. Write the chemical equation for the reaction you observed. Record the initial and final mass of the substance in the container.

D. Click on the Return button to go back to the first screen. Then click on the Advance button to return to the second screen. Click on the Start button to collect a second set of data. Repeat this process until you have six sets of data. Record these data in the table below.

Initial Mass	Final Mass	Change in Mass

II. Data Analysis Interpretation and Conclusions

A. What chemical substance is represented by the initial mass? What chemical substance is represented by the final mass? What chemical substance is represented by the change in mass?

B. Plot a graph of the initial mass by the change in mass and determine the equation of the line. Record your results below. Include the graph in your report. (If you have a straight line, you can use the equation for a straight line ($y = mx + b$). If the line is a curved line, you can test to see if the plot is a power function ($y = x^n$) or a logarithmic function ($y = \log x$). This can be made easier if you are using a graphing or data analysis program like Excel™. Your instructor can show you how to do this.)

C. Rewrite the equation to represent the mass relationships between chemical substances (substitute chemical formulas for x and y). What does the slope of the line represent?

D. Determine the value for x in the formula $CuSO_4(H_2O)_x$. (Remember that x is numbers of particles, not mass.)

BURNING A HYDROCARBON I

Name ______________________ Section ______________

Problem Statement: How are masses of reactants and products related?

I. Data Collection

A. Go to http://introchem.chem.okstate.edu/DCICLA/stoic_excess_oxy.html and open the Burning a Hydrocarbon I Simulation. Your screen should look like the figure below.

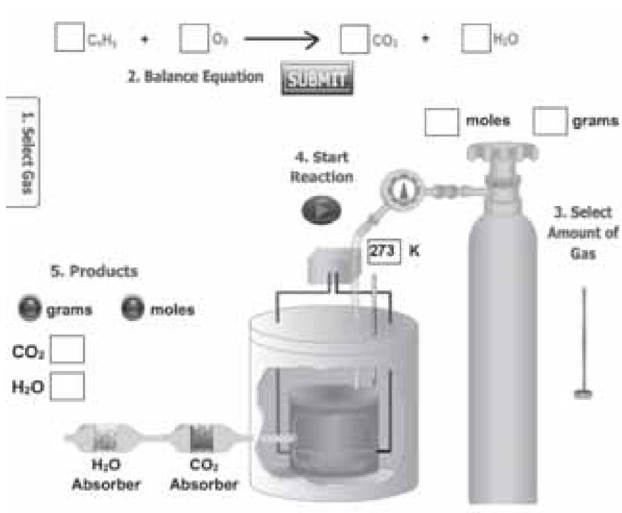


Figure 1.

The apparatus represents a reaction container that can be filled with different amounts of hydrocarbon gases from a gas cylinder. A hydrocarbon is a chemical substance containing only hydrogen and carbon. When hydrocarbons combine with oxygen, (i.e., burn), they produce carbon dioxide and water as products. The reaction container will also hold oxygen gas to react with the hydrocarbon. To use the simulation you must (1) select a gas by clicking on the select tab, (2) balance the chemical equation and submit it, (3) specify the amount of gas with a slide bar, (4) start the reaction, and (5) examine the amount of products. These steps are numbered in the simulation.

B. Click on the Select Gas tab and pick CH_4, methane. Balance the equation using the lowest ratio of whole numbers and submit the equation. Add 10.0 g of CH_4 to the reaction container and start the reaction. The simulation will burn the gas and pass the products through filters that will absorb the product molecules so that they can be weighed. Click on the Product button. Record the data you collected in the following tables.

	___CH_4 +	___O_2 →	___CO_2 +	___H_2O
Initial Amount (moles) – I		—		
Change (moles) – C				
Ending Amount (moles) – E		—		

Initial Amount (grams) – I		—		
Change (grams) – C				
Ending Amount (grams) – E		—		

C. Calculate the change in the number of moles and grams that occurred when the reaction was complete. Record your results in the tables above.

II. Data Analysis and Interpretation

A. What must you assume about the amount of oxygen present in the reaction container at the beginning of the reaction to account for your observations?

B. How do you know that all of the CH_4 reacted when the reaction was complete?

C. Compare the total mass of the compounds that reacted with the total mass of the products that was formed.

D. Compare the balanced equation to the data in the tables. Which data best describes the relationships represented by the balanced equation?

III. Data Collection

A. Click on the Select Gas tab and pick C_2H_6, ethane. Balance the equation using the lowest ratio of whole numbers and submit the equation. Add 10.0 g of C_2H_6 to the reaction container and start the reaction. Click on the Product button. Record the data you collected in the following tables.

	___C_2H_6 +	___O_2 →	___CO_2 +	___H_2O
Initial Amount (moles) – I		—		
Change (moles) – C				
Ending Amount (moles) – E		—		

Initial Amount (grams) – I		—		
Change (grams) – C				
Ending Amount (grams) – E		—		

B. Calculate the change in the number of moles and grams that occurred when the reaction was complete. Record your results in the tables above.

IV. Data Analysis and Interpretation

A. Compare the total mass of the compounds that reacted with the total mass of the products that was formed. Is mass conserved?

B. Compare the total number of moles of the compounds that reacted with the total number of moles of the products that were formed. Is the number of moles conserved?

V. Data Collection

A. Consider burning 10.0 g C_3H_8, propane. Balance the following equation using the lowest ratio of whole numbers. Before trying the experiment, predict the amounts of reactants and products and fill in the tables below.

	___C_3H_8 +	___O_2 →	___CO_2 +	___H_2O
Initial Amount (moles) – I		—		
Change (moles) – C				
Ending Amount (moles) – E		—		

Initial Amount (grams) – I		—		
Change (grams) – C				
Ending Amount (grams) – E		—		

B. Test your predictions using the simulation. Correct any values in the table.

VI. Conclusions

A. Compare the total mass of the compounds that reacted with the total mass of the products that were formed. Is mass conserved?

B. Compare the total number of moles of the compounds that reacted with the total number of moles of the products that were formed. Is the number of moles conserved?

C. Click on the Select Gas tab and pick unknown hydrocarbon C_xH_y. Add 10.0 g of C_xH_y to the reaction container and start the reaction. Click on the Product button. Record the data you collected in the following tables.

	____C_xH_y +	____O_2 →	____CO_2 +	____H_2O
Initial Amount (grams) – I		—		
Change (grams) – C				
Ending Amount (grams) – E		—		

Initial Amount (moles) – I		—		
Change (moles) – C				
Ending Amount (moles) – E		—		

D. Determine possible values for x and y. Balance the equation using the resulting hydrocarbon.

____ ____ + ____O_2 → ____CO_2 + ____H_2O

BURNING A HYDROCARBON II

NAME ______________________ SECTION ______________

Problem Statement: How are the masses of products limited by the amounts of reactants?

I. Data Collection

A. Go to http://introchem.chem.okstate.edu/DCICLA/stoic_select_both.html and open the Burning a Hydrocarbon II Simulation. Your screen should look like the figure below.

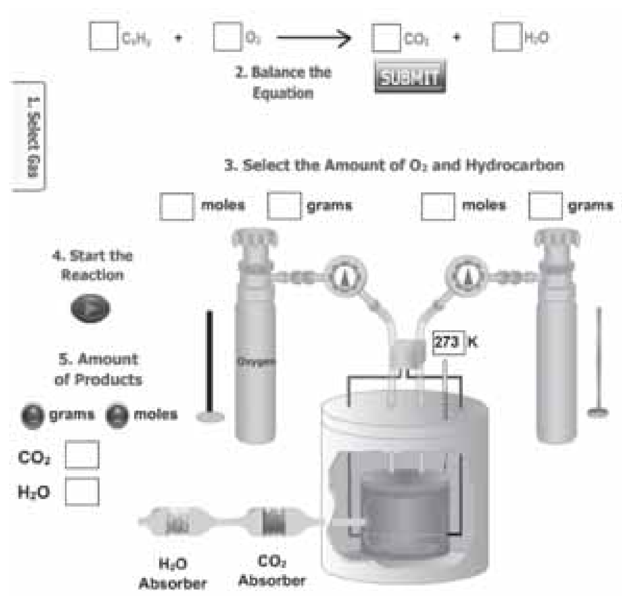


Figure 1.

The apparatus represents a reaction container that can be filled with different amounts of hydrocarbon gases from a gas cylinder and different amounts of oxygen from a second gas cylinder. A hydrocarbon is a chemical substance containing only hydrogen and carbon. When hydrocarbons combine with oxygen, (i.e., burn), they produce carbon dioxide and water as products. To use the simulation you must (1) select a gas by clicking on the select tab, (2) balance the chemical equation and submit it, (3) specify the amount of hydrocarbon gas and oxygen gas with slide bars, (4) start the reaction, and (5) examine the amount of products. These steps are numbered in the simulation.

B. Click on the Select Gas tab and pick CH_4, methane. Balance the equation using the lowest ratio of whole numbers and submit the equation. Add 100 g of CH_4 and 100 g of O_2 to the reaction container and start the reaction. The simulation will burn the gas and pass the products through filters that will absorb the product molecules so that they can be weighed. Click on the Product button. Record the data you collected in the following tables.

$$\_\_\_\_CH_4 + \_\_\_\_O_2 \rightarrow \_\_\_\_CO_2 + \_\_\_\_H_2O$$

Masses in Grams			
Reactants		Products	
O_2	CH_4	CO_2	H_2O
100	100		
100	90		
100	80		
100	70		
100	60		
100	50		
100	40		
100	30		
100	20		
100	10		

Moles			
Reactants		Products	
O_2	CH_4	CO_2	H_2O

C. Repeat the experiment, reducing the amount of CH_4 while keeping the amount of O_2 the same. Use the amounts shown in the table. Record the data you collected in the above tables.

II. Data Analysis and Interpretation

A. Plot the mass of CH_4 vs. the masses of CO_2 and H_2O. Explain the shape of the plot in terms of the chemical reaction.

B. Connect the points on the graph by drawing two straight lines. What is the significance of the point where the two lines intersect? Include the graph in your report.

C. Plot the moles of CH_4 vs. the moles of CO_2 and H_2O. Connect the points on the graph by drawing two straight lines. What is the significance of the point where the two lines intersect? How is this point related to the balanced chemical equation for this reaction? Include the graph in your report.

D. A limiting reagent is the reactant in a chemical reaction that controls the amount of products that can be produced. It "limits" the amount of product. Other reagents are said to be "in excess." What is the limiting reagent and what reagent is in excess: (a) when 100 g of O_2 and 100 g of CH_4 are reacted, (b) when 100 g of O_2 and 50 g of CH_4 are reacted, and (c) when 100 g of O_2 and 10 g of CH_4 are reacted? How much excess in each case?

III. Data Collection

A. Click on the Select Gas tab and pick C_2H_6, ethane. Balance the equation using the lowest ratio of whole numbers and submit the equation. Add 100 g of O_2 and 10.0 g of C_2H_6 to the reaction container and start the reaction. The simulation will burn the gas and pass the products through filters that will absorb the product molecules so that they can be weighed. Click on the Product button. Record the data you collected in the following tables.

$$\_\_\_\_ C_2H_6 + \_\_\_\_O_2 \rightarrow \_\_\_\_CO_2 + \_\_\_\_H_2O$$

Masses in Grams			
Reactants		Products	
O_2	C_2H_6	CO_2	H_2O
100	10		
90	20		
80	30		
70	40		
60	50		
50	60		
40	70		
30	80		
20	90		
10	100		

Moles			
Reactants		Products	
O_2	C_2H_6	CO_2	H_2O

B. Repeat the experiment, reducing the amount of O_2 while increasing the amount of CH_4. Use the amounts shown in the table. Record the data you collected in the above tables.

IV. Data Analysis and Interpretation

A. Plot the masses of O_2 and C_2H_6 vs. the masses of CO_2 and H_2O on the same graph. Explain the shape of the plots in terms of the chemical reaction. Connect the points on the graph by drawing two straight lines. What is the significance of the points where the two lines intersect? Include the graph in your report.

B. Plot the moles of O_2 and C_2H_6 vs. the moles of CO_2 and H_2O on the same graph. Connect the points on the graph by drawing two straight lines. What is the significance of the point where the two lines intersect? How is this point related to the balanced chemical equation for this reaction? Include the graph in your report.

C. Identify the limiting reagent when you have an equal number of grams of the reactants.

V. Conclusions

A. If you burned 100 g of C_2H_6 with 100 g of O_2, how many grams of CO_2 and H_2O would be formed? How many grams of C_2H_6 and O_2 would be in excess?

B. Check your predictions with the simulation.

HEATS OF SOLUTION

Name ______________________ Section ____________

Problem Statement: How is heat energy related to the dissolving process?

I. Data Collection

A. Go to http://introchem.chem.okstate.edu/DCICLA/heat_soln.html and open the Heat of Solution Simulation. Your screen should look like the figure below.

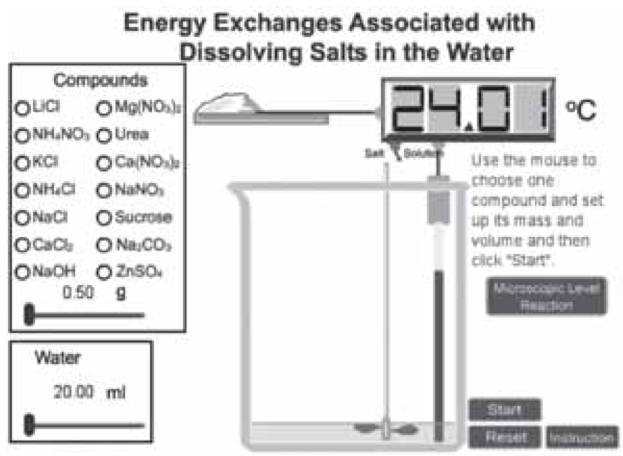


Figure 1.

The apparatus represents a beaker that can be filled with different amounts of water. Different amounts of various soluble solids can be added to the beaker. The amounts are controlled by slide bars. A temperature gauge monitors the temperature of the contents of the beaker. A microscopic representation of the dissolving process can be accessed by a microscopic level button.

B. Use the button to pick LiCl. Leave the water volume at 20 mL and the amount of LiCl at 0.50 g. Record the beginning condition of the solution in the table below.

Compound	Mass of Solution	Mass of Compound	Initial Temperature	Final Temperature	Change in Temperature
LiCl	20 mL	0.50 g			
NH_4NO_3	20 mL	0.50 g			
KCl	20 mL	0.50 g			
NH_4Cl	20 mL	0.50 g			
NaCl	20 mL	0.50 g			
$CaCl_2$	20 mL	0.50 g			
NaOH	20 mL	0.50 g			
$Mg(NO_3)_2$	20 mL	0.50 g			
Urea	20 mL	0.50 g			
$Ca(NO_3)_2$	20 mL	0.50 g			
$NaNO_3$	20 mL	0.50 g			
Sucrose	20 mL	0.50 g			
Na_2CO_3	20 mL	0.50 g			
$ZnSO_4$	20 mL	0.50 g			

C. Click on the Start button. What do you observe happening? Record the final conditions of the solution in the table above.

D. Repeat the experiment for each of the compounds in the list. Record your data in the table above.

II. Data Analysis and Interpretation

A. Which compounds release heat when they dissolve? (This is termed an exothermic process.) Which compounds gain heat when they dissolve? (This is called an endothermic process.)

B. How are the compounds that didn't gain or release heat when they dissolved different from those that did?

C. An animation that models the dissolving process for ionic salts can be viewed by clicking on the Microscopic Level Reaction button. Describe in your own words this process. Write a chemical equation representing the process of LiCl dissolving (LiCl(s) $\rightarrow$?). Write a chemical equation representing the process of $CaCl_2$ dissolving. Write a chemical equation representing the process of $Mg(NO_3)_2$ dissolving. How many dissolved particles result from one particle of each compound?

D. Consider the following statements made by students about this experiment. Are these statements true or false? Provide evidence for your conclusions.

The number of dissolved particles (ions or moles of ions) is related to the temperature change.

Certain cations are associated with either exothermic or endothermic processes.

Certain anions are associated with either exothermic or endothermic processes.

The amount of heat gained or released by a compound is different for different compounds.

III. Data Collection

A. Set the volume of the water at 100 mL and the mass of LiCl at 0.50 g. Click on the Start button. Record the data in the table below. Repeat this experiment four more times with masses between 1.00 and 5.00 grams. Record the data in the table below.

Mass of Compound	Mass of Solution	Initial Temp	Final Temp	Change in Temp

IV. Data Analysis and Interpretation

A. Test to see if the temperature change is related to the mass of compound by plotting them on a graph and determining the equation of the line. Record your results below. Include the graph in your report. (If you have a straight line, you can use the equation for a straight line ($y = mx + b$). If the line is a curved line, you can test to see if the plot is a power function ($y = x^n$) or a logarithmic function ($y = \log x$). This can be made easier if you are using a graphing or data analysis program like Excel™. Your instructor can show you how to do this.)

B. Express the equation you determined in the previous section in units of °C/g. Do you expect this value to be the same for the other compounds? What would you expect the temperature change would be if you had dissolved 8.50 g of LiCl in 100 mL of water?

C. Determine the change in temperature if you dissolved 8.50 g of NaOH in 100 mL of water.

D. Using the data you collected in the above experiment, make a statement that summarizes the relationship between the heat energy when LiCl dissolves and the temperature change of the solution.

V. Data Collection

Set the volume of the water at 20 mL and the mass of LiCl at 0.50 g. Click on the Start button. Record the data in the table below. Repeat this experiment four more times with volumes of water between 30 mL and 200 mL. Record the data in the table below.

Mass of Compound	Mass of Solution	Initial Temp	Final Temp	Change in Temp
0.50 g				
0.50 g				
0.50 g				
0.50 g				
0.50 g				

VI. Data Analysis and Interpretation

A. Considering that the amount of LiCl is the same in each trial, what can you say about the amount of heat energy released when the LiCl dissolves in water. How do you account for any differences in the temperature changes?

B. Compare the amount of heat energy gained by the water solution in each of the five trials. What accounts for this comparison?

C. How is heat gained by the water solution related to the temperature change?

VII. Conclusions

A. You can assume that the heat (given the symbol "q" and expressed in units of Joules) that is lost or gained by the compounds studied in this activity is equal to the heat gained or lost by the solution (mostly water). If this is correct, you can measure the heat of the solution process for a compound by measuring the heat gained by the solution/water. Considering the results of the previous section of this activity, what factors control how much heat is gained or lost by the solution/water ($q \propto$? and ?).

B. Water, as is true of all substances, has a characteristic ability to gain or lose heat. A measure of this ability is expressed as the specific heat content (C_s). (C_s can be used as a proportionality constant to change the $\propto$ sign from the previous section to an = sign.) This constant has a value for water of 4.184 J/g-°C. Write the equation for the heat (q = ?) when LiCl is dissolved in 20 mL of water. Calculate how much heat LiCl releases per gram.

HEAT TRANSFER

NAME SECTION

Problem Statement: How is heat transferred between substances?

I. Data Collection

A. Go to http://introchem.chem.okstate.edu/DCICLA/heat_metal_ice.html and open the Heat Transfer Simulation. Your screen should look like the figure below.

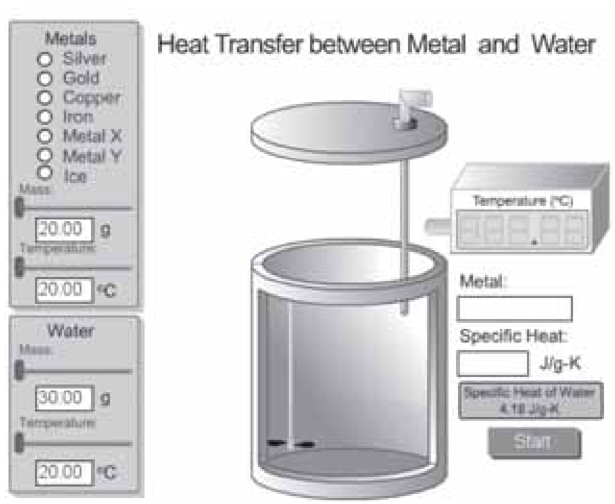


Figure 1.

The apparatus represents a container that can be filled with different amounts of water at different temperatures. Different amounts of various substances at different temperatures can be added to the water. Slide bars control these amounts. A temperature gauge monitors the temperature of the contents of the container. The specific heat content (C_s) of the water and the added substances are displayed in boxes.

B. Use the button to pick Ag. Adjust its temperature to 220.00 °C and its mass to 20.0 g. Adjust the water temperature to 20.00 °C and its mass to 30.00 g. Record the beginning conditions in the table below.

	Ag	Water
Mass		
Initial Temp		
Final Temp		
Change in Temp		
Heat Content		

C. Click on the Start button. What do you observe happening? Record the final conditions of Ag and the water in the table above.

II. Data Analysis and Interpretation

A. Which substance, Ag or water, loses heat when they are combined? Which substance, Ag or water, gains heat when they are combined? Which process is endothermic and which is exothermic?

B. Calculate the heat (q) transferred to or from Ag. Use the equation $q = mC_s\Delta t$ (q is heat in Joules, m is mass, C_s is the heat content, and Δt is the change in temperature).

C. Calculate the heat (q) transferred to or from water.

D. Compare the heats associated with the Ag and water. Make a generalization concerning these heats.

E. How would your results have been different if you had used different amounts of Ag and water starting at different temperatures? Try this out and report your results.

III. Data Collection

Repeat the experiment for Au, Cu, and Fe. Record the data you collect in the following table.

	Au	Water	Cu	Water	Fe	Water
m						
t_i						
t_f						
Δt						
C_s						
q						
molar heat capacity						

IV. Data Analysis and Interpretation

A. Calculate the heat lost or gained by each metal. Show your work for one of the calculations below.

B. Compare the results for all four metals. How are these metals different from each other?

C. Which of these metals would make the best cookware? Explain your answer.

D. Calculate the molar heat capacity for Au, Cu, and Fe in units of $\frac{J}{mol \bullet {}^{0}C}$. Record the value in the table on the previous page. Compare the molar heat capacity for each of the metals.

V. Conclusions

A. Repeat the experiment for the unknown metals. Record the data you collect in the following table.

	Metal X	Water	Metal Y	Water
m				
t_i				
t_f				
Δt				
C_s				
q				

B. Calculate values for the heat contents for the two unknown metals.

C. Based on the comparison you made in IV.D., estimate the molar heat capacity for each unknown metal.

D. Calculate the molar mass of each unknown metal.

E. Assuming the unknown metals are pure substances, identify them. Show how you arrived at your answers below.

Name | Section

Problem Statements: How are the electrons in an atom arranged? How is the arrangement of electrons in an atom related to the periodic table?

I. Data Collection

A. A. Go to http://introchem.chem.okstate.edu/DCICLA/aufbau.swf and open the Aufbau Simulation. Your screen should look like the figure below.

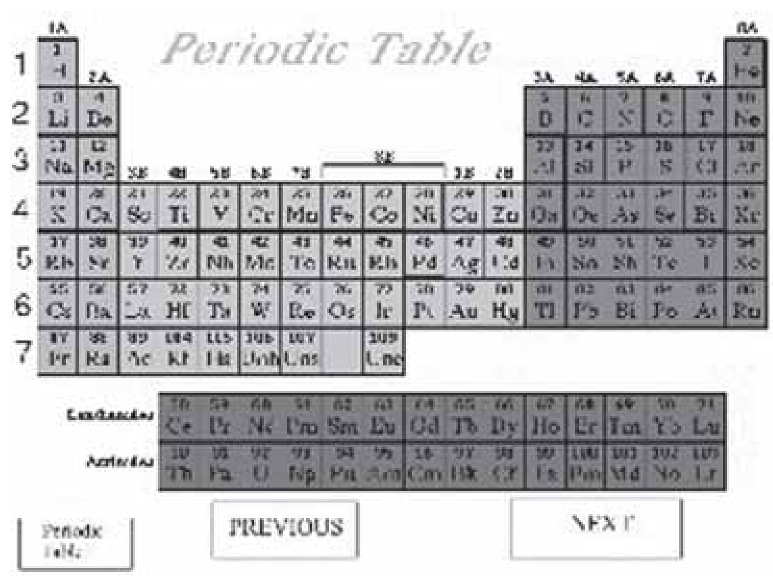
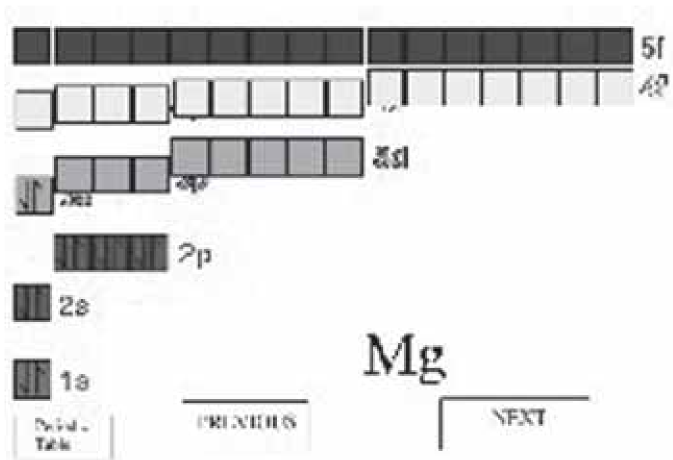


Figure 1.

This window will give you access to the energy level diagrams for many of the elements of the periodic table. Each element square from element 1, H, to element 48, cadmium, will display the locations of each of the electrons in an atom of the element. Click on the box for element 12, magnesium. Your screen should look like the figure below.



B. Click on the "Periodic Table" button to return to the periodic table window and click on the "NEXT" button. The diagram represents the energy levels of atoms from the lowest energies to higher energies. Sketch the diagram below.

C. Each box in the diagram is called an orbital and represents the region in space that the electrons in an atom can occupy. The numbers in the diagram label the energy level of the orbital from lowest (1) to higher (5) and the letters identify the type of orbital at each level. Orbital types are grouped together in the diagram and have specified letters. How many s orbitals are there at each energy level? How many p orbitals are at each energy level? How many d orbitals are at each energy level? How many f orbitals are there at each energy level? Fill in the following table with your results.

Energy Level	s orbitals	p orbitals	d orbitals	f orbitals
1				
2				
3				
4				
5				

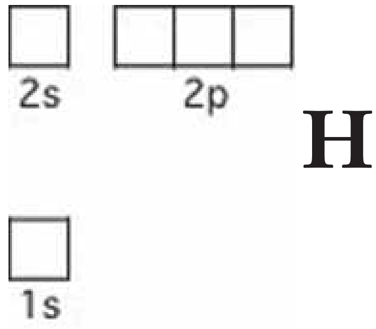
II. Data Analysis, Interpretation, and Conclusions

A. Speculate on why there are more orbitals at higher energy levels. (Consider what happens to the geometry of an atom in three-dimensional space as one gets further from the nucleus.)

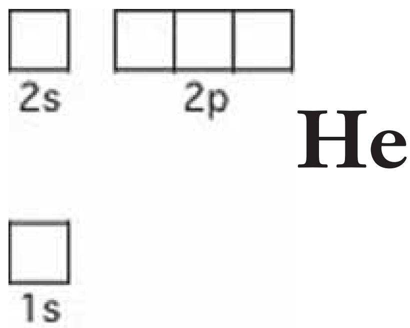
B. Speculate why some orbital types have more orbitals at each energy level. How might s and p orbitals be different so as to account for different numbers? (The three p orbitals are named p_x, p_y, and p_z.)

III. Data Collection

A Click on the "NEXT" button to display the hydrogen atom. Sketch what you see in the diagram.



B. Click on the "NEXT" button to display the helium atom. Sketch what you see in the diagram.



IV. Data Analysis and Interpretation

A. What do the arrows in the orbitals represent?

B. Why are the arrows pointed in opposite directions? What does the direction of the arrows represent? (Electrons can be thought of as particles that rotate on an axis.)

C. Electrons have common negative charges and consequently repel each other. Why would the second electron in helium go into the same orbital as the first electron instead of a different orbital?

D. The next element is lithium. Where would the next arrow go? Why?

V. Conclusions

A. What are the maximum numbers of electrons that can be put into an orbital? What must be true of these electrons to be able to occupy the same orbital? How is it possible for two electrons to occupy the same space?

B. Why do the electrons for helium fill into the 1s orbital? Why don't they fill into the second or third level? What would be necessary for these electrons to fill into the second level?

C. Locate helium on the periodic table. How many atoms are in the first period (row) of the periodic table? How many atoms are accommodated by the available orbitals in the first energy level? How are the energy levels of the orbitals related to the periodic table?

VI. Data Collection

A. Click on the "NEXT" button to display the lithium atom. Sketch what you see for the first and second energy levels.

B. Predict into which orbital the next electron (representing the beryllium atom) will go. Click on the "NEXT" button to display the Be atom. Sketch what you see for the first and second energy levels.

VII. Data Analysis and Interpretation

A. Why does the third electron representing lithium go into the 2s orbital? Why doesn't it go into one of the 2p orbitals?

B. Why does the fourth electron representing beryllium go into the 2s orbital? Why doesn't it go into one of the 2p orbitals?

C. The next element is boron. Where would the next electron go? Why?

VII. Conclusions

A. Speculate why there are three p orbitals but only one s orbital. How are the shapes of s and p orbitals different? Why do the three p orbitals remain at equal energies?

B. Speculate why there are p orbitals at the second energy level, but not at the first energy level.

VIII. Data Collection

A. Click on the "NEXT" button to display the boron atom. Sketch what you see for the first and second energy levels.

B. Predict into which orbital the next electron (representing the carbon atom) will go. Click on the "NEXT" button to display the C atom. Sketch what you see for the first and second energy levels.

IX. Data Analysis and Interpretation

A. Speculate why the 2s and 2p orbitals have different energies in Boron.

B. Why does the sixth electron, representing the element carbon, go into an empty p orbital instead of doubling up as the electrons did in the s orbitals?

C. Consider the relative energies that the 2s and 2p orbitals have. How are they different for B and C? How would you account for any difference? (Using the "PREVIOUS" and "NEXT" buttons, toggle between B and C to see the difference.)

D. Why is the electron for boron placed in the left p orbital? Is there any reason to believe that that orbital has less energy than the other p orbitals?

X. Conclusions

A. The next atom is nitrogen. Predict where the electron will be placed and what will happen to the relative energies of the 2s and 2p orbitals.

B. Predict where the next three electrons for atoms oxygen, fluorine, and neon will be placed. Sketch what you would see for the first and second energy levels for Ne. Confirm your predictions.

C. Locate Ne on the periodic table. How many atoms are accommodated by the available orbitals in the second energy level? How are the energy levels of the orbitals related to the periodic table?

D. Predict where the 11th electron representing the element sodium will be placed. Sketch how the orbitals at the third energy level will look when you view the diagram for Na.

XI. Data Collection

A. Click on the "NEXT" button to display the atoms from Na to Ar. Record your observations concerning how the orbitals are filled and how the added electrons influence the energies of the orbitals at the third energy level.

B. Sketch the diagram for the argon atom.

C. The next atom is potassium. Predict where the 19th electron will be placed. Confirm your prediction and sketch a diagram of the 3rd and 4th energy levels for K.

XII. Data Analysis, Interpretation, and Conclusions

A. Why does the 19th electron representing the potassium atom enter the s orbital in the 4th energy level instead of the d orbital in the 3rd energy level?

B. Locate argon on the periodic table. How many atoms are accommodated by the third period (row) of the periodic table? How is this related to the energy level diagram?

C. How does the location of K on the periodic table account for the location of the 19th electron in the energy level diagram?

XIII. Data Collection

A. Click on the "NEXT" button to display the atoms from K to V. Record your observations concerning how the orbitals are filled and how the added electrons influence the relative energies of the 4s and 3d orbitals.

B. Sketch your prediction for the electron distribution in the 4s and 3d orbitals for the Cr atom.

C. Click on the "NEXT" button to display the chromium atom. Record your observations concerning how the orbitals are filled. Sketch the diagram for the third and fourth energy levels for the Cr atom.

D. Click on the "NEXT" button to display the atoms from chromium to nickel. Record your observations concerning how the orbitals are filled.

E. Click on the "NEXT" button to display the atom copper. Record your observations concerning how the orbitals are filled. Sketch the diagram for the third and fourth energy levels for the Cu atom.

F. Click on the "NEXT" button to display the atom zinc. Record your observations concerning how the orbitals are filled.

G. Click on the "NEXT" button to display the atoms from gallium to krypton. Record your observations concerning how the orbitals are filled.

XIV. Data Analysis and Interpretation

A. Speculate why the energies of the 4s and 3d orbitals become equalized as electrons are added to the atoms from K to Cr.

B. Rationalize the electron arrangement of Cr. Why does the electron arrangement of Cr have a half-filled 4s orbital rather than a filled 4s orbital?

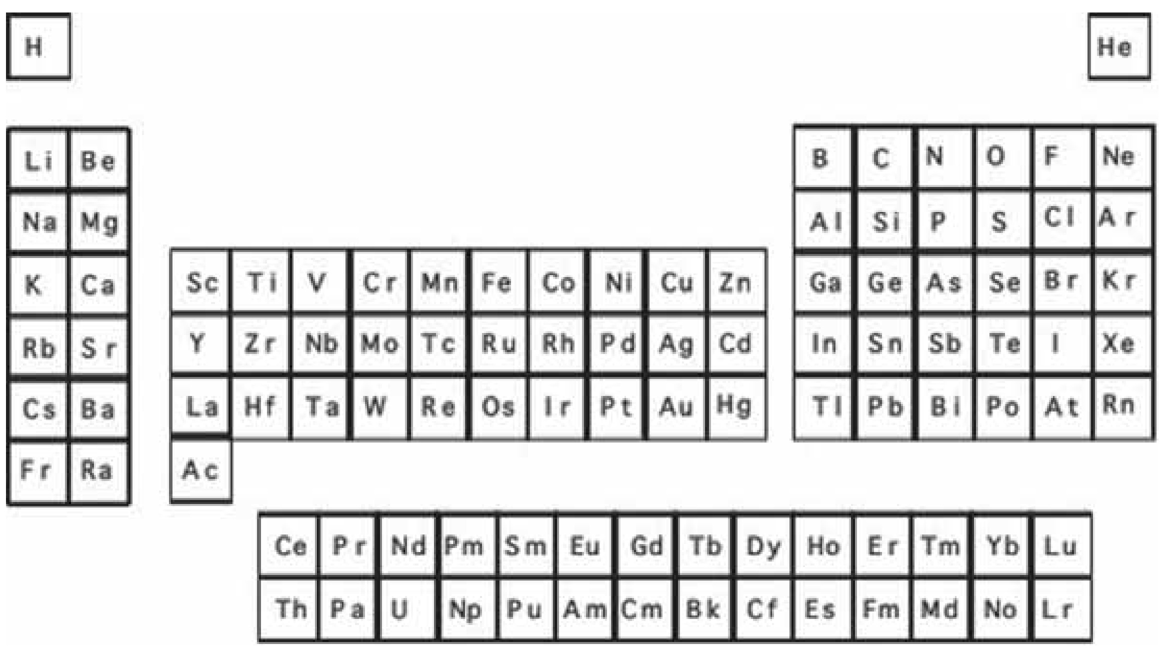
C. Rationalize the electron arrangement of Cu. Why does the electron arrangement of Cu have a half-filled 4s orbital rather than a filled 4s orbital? How might you account for the Cu+ and Cu2+ ions using different possible electron arrangements in the 4s and 3d orbitals?

XV. Conclusions

A. Consider the elements Sc through Zn on the periodic table. What orbitals and energy levels do these elements represent?

B. Locate krypton on the periodic table. How many atoms are accommodated by the fourth period (row) of the periodic table? How is this related to the energy level diagram? Count the number of atoms in the fourth period. How is this number related to the number of orbitals utilized by these elements?

C. Label the periods (rows) of the periodic table in the following diagram with the corresponding energy level, and the families (columns) with the corresponding orbitals. (The two rows at the bottom of the table represent f electrons.)



D. The two rows at the bottom of the periodic table (called the lanthanides and actinides) can be inserted into the main body of the periodic table after elements 57 and 89 (see the sequence of the atomic numbers for these elements). The atoms of these elements have electrons entering f orbitals. What orbitals are filled right before the 4f orbitals?

PRESSURE–VOLUME RELATIONSHIPS

Name ______________________ Section ______________________

Problem Statement: How are pressure and volume of a gas sample related?

I. Data Collection

A. Go to http://introchem.chem.okstate.edu/DCICLA/boyles_law_graph.html and open the Pressure–Volume Simulation. Your screen should look like the figure below.

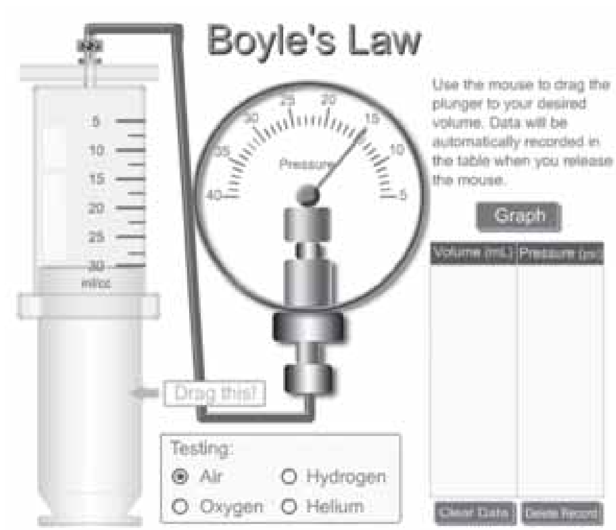


Figure 1.

The apparatus represents a syringe that can be filled with four different gases. The gas volume can be changed by click/dragging the piston to compress the gas.

B. Click the button to the left of the Air gas. Drag/click the piston of the syringe to compress the gas as much as possible. Release the mouse button and then click on the piston as it returns to its original position eight times. Record the data you collected in the table below. Convert the pressure units to atm (14.7 psi = 1 atm).

Volume (mL)	Pressure (psi)	Pressure (atm)

II. Data Analysis and Interpretation

A. Plot the volume (mL) of the air sample vs. its pressure (atm) and determine the equation of the line. Record your results below. Include the graph in your report. (If you have a straight line you can use the equation for a straight line ($y = mx + b$). If the line is a curved line, you can test to see if the plot is a power function ($y = x^n$) or a logarithmic function ($y = \log x$). This can be made easier if you are using a graphing or data analysis program like Excel™. Your instructor can show you how to do this.)

B. Write an algebraic equation showing the relationship between volume and pressure of the air sample. This relationship is known as Boyle's Law. If the volume of the sample of air you are studying was expanded to 50 mL, what would its pressure be?

C. Mental Modeling: At the level of atoms and molecules, what factors cause a change in the pressure as the volume is changed?

III. Data Collection

A. Repeat the experiment in section I, using hydrogen instead of air. Record the data you collected in the table below. Convert the pressure units to atm.

Volume (mL)	Pressure (psi)	Pressure (atm)

B. Repeat the experiment in section I, using oxygen instead of air. Record the data you collected in the table below. Convert the pressure units to atm.

Volume (mL)	Pressure (psi)	Pressure (atm)

C. Repeat the experiment in section I, using helium instead of air. Record the data you collected in the table below. Convert the pressure units to atm.

Volume (mL)	Pressure (psi)	Pressure (atm)

IV. Data Analysis and Interpretation

A. Plot the volume (mL) of the gas samples of hydrogen, oxygen, and helium vs. their pressures (atm) on the same graph as you plotted for the air sample. How are the graphs and algebraic equations for these four gases related?

B. Mental Modeling: At the level of atoms and molecules, account for the relationship between these four gases.

V. Conclusions

A. How do the differences in molar mass effect the pressure volume relationship between the four gases?

B. Write an algebraic equation that relates the pressure volume relationship for all four of these gases.

NAME ______________________ SECTION ______________

Problem Statement: How are temperature and volume of a gas sample related?

I. Data Collection

A. Go to http://introchem.chem.okstate.edu/DCICLA/charles_law.html and open the Volume–Temperature Simulation. Your screen should look like the figure below.

Figure 1.

The apparatus represents a container that is filled with a gas. The gas is confined in the container by a movable weight. The volume of the gas can change with temperature so that the pressure on the gas exerted by the weight remains constant. The temperature can be changed by using the slide bar under the target temperature box. You can expose a table that shows the temperature and volume data you collect by clicking on the "Show Data Table" box.

B. Open the "Show Data Table" window. Using the slider bar, increase the temperature of the gas container. Describe what you observe happening.

C. When the temperature in the container reaches the target temperature, record the volume and temperature data in the table below. Collect 5 more data points for temperatures between 450 and 75 K. Convert the temperature to °C.

Volume (mL)	Temperature (K)	Temperature (°C)

II. Data Analysis and Interpretation

A. Plot the temperature (°C) of the air sample vs. its volume (mL) and determine the equation of the line. Record your results below. Include the graph in your report. (If you have a straight line you can use the equation for a straight line ($y = mx + b$). If the line is a curved line, you can test to see if the plot is a power function ($y = x^n$) or a logarithmic function ($y = \log x$). This can be made easier if you are using a graphing or data analysis program like Excel™. Your instructor can show you how to do this.)

B. Write an algebraic equation showing the relationship between temperature and volume of the air sample (V = ?). This relationship is known as Charles' Law. If the gas sample were cooled until the volume approaches zero mL, what would its temperature be, in both °C and K?

C. What could be done to lower the temperature below that in section II.B?

D. Mental Modeling: At the level of atoms and molecules, what factors cause a change in the volume as the temperature is changed? What happens to these atoms/molecules when the temperature is lowered to the temperature that you calculated in II.B?

EFFUSION

Name ______________________ Section ______________

Problem Statement: How fast do gases escape from a container?

I. Data Collection

A. Go to http://introchem.chem.okstate.edu/DCICLA/effusion_macro.html and open the Effusion Simulation. Your screen should look like the figure below.

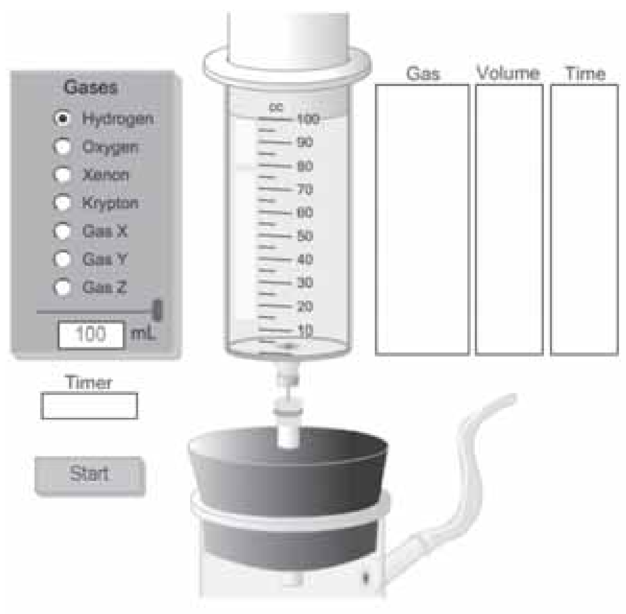


Figure 1.

The apparatus represents a syringe that can be filled with different gases, including some unknown gases, to a volume that you can specify. The syringe is connected to a flask by a needle with a very small opening. The flask is connected to a vacuum pump that removes any gases that are in the system. The process of a gas escaping through a small hole into a vacuum is called effusion.

B. Use the button to pick hydrogen gas. Leave 100 mL as the volume. Click on the Start button and allow the gas to escape into the flask. Record what you observe happening.

C. Adjust the volume of hydrogen gas to 75 mL with the slider bar and repeat the experiment. Do the same for 50 mL and 25 mL of hydrogen. Record the amount of time for the gas to escape from the syringe in the table below.

Gas	Volume	Time	Rate
Hydrogen	100 mL		
Hydrogen	75 mL		
Hydrogen	50 mL		
Hydrogen	25 mL		

The rate of a process is defined as the change of an amount per the elapsed time. For example, the rate of speed of an automobile is the change of distance (miles) per unit time (hours). What is the rate (called the rate of effusion) that hydrogen gas escapes from the syringe in this experiment? Record these values in the table above.

II. Interpretation

A. What is the unit of the rate of effusion in this experiment?

B. Mental Modeling: At the level of atoms and molecules, explain how hydrogen molecules escape from the syringe. What factor(s) control how fast the molecules escape? How could you increase the rate of effusion in this experiment?

III. Data Collection

Set the volume of the syringe at 100 mL and measure the rate of effusion for all of the gases. Record the data in the table below. Record the molecular masses of the gases in the table.

Gas	MM	Volume	Time	Rate
Hydrogen		100 mL		
Oxygen		100 mL		
Xenon		100 mL		
Krypton		100 mL		
Gas X		100 mL		
Gas Y		100 mL		
Gas Z		100 mL		

IV. Data Analysis and Interpretation

A. Account for any differences in the rates of effusion for the different gases. Why do some gases effuse faster than others? Can you use the kinetic molecular theory to justify your answer?

B. Test to see if the rate of effusion is related to the molecular weight of the gases by plotting them on a graph and determining the equation of the line. Record your results below. Include the graph in your report. (If you have a straight line, you can use the equation for a straight line ($y = mx + b$). If the line is a curved line, you can test to see if the plot is a power function ($y = x^n$) or a logarithmic function ($y = \log x$). This can be made easier if you are using a graphing or data analysis program like Excel™. Your instructor can show you how to do this.)

C. From your graph determine the molecular weights of the unknown gases. Propose the possible identities of the unknown gases.

V. Conclusion

Propose an equation that will relate the rates of effusion of two gases. This equation could be used to determine the molecular weight of an unknown gas by comparing its rate of effusion with the rate of effusion of a known gas ([rate unknown gas] / [rate known gas] = ?). How is this equation related to the kinetic molecular theory?